



IMPERIAL AGRICULTURAL
RESEARCH INSTITUTE, NEW DELHI.

18860

MOH. 450-III 1961 2 3 40-50000

SCIENTIFIC AGRICULTURE

LA REVUE AGRONOMIQUE CANADIENNE

VOLUME 25

September 1944 - August 1945

EDITED BY
CANADIAN SOCIETY OF TECHNICAL AGRICULTURISTS AT
OTTAWA, CANADA

*Published monthly by the authority of the
Chairman of the National Committee on Agricultural Services*

18860

SUBJECT INDEX TO VOLUME 25

	Page
Acidity: Its relation to butter flavour.....	137
Acid-oxalate extracts of podzol and podzolic soils, The.....	215
Acrididae of Alberta, A contribution to the knowledge of the.....	577
Agronomic and quality characteristics of Carleton durum wheat grown in the durum wheat area of Western Canada.....	107
Analysis of horticultural soils.....	175
Apple scab in Ontario, An appraisal of spray materials for the control of.....	680
Apple yields in Okanagan Valley. Some factors affecting	
I. Tree size, tree vigour, biennial bearing, and distance of planting.....	189
Appraisal of spray materials for the control of apple scab in Ontario, An.....	680
<i>Argyrotaenia</i> Stephens (Lepidoptera, Tortricidae), A review of the North American species of the genus.....	81
Bacon hog ration, Barley vs. wheat as the basal feed in the.....	403
Bacon hogs, III, The digestibility of typical Eastern Canadian feeds by market.....	43
Bacon type hogs, Growth of. Rates of gain at specific live weights.....	854
Barley vs. wheat as the basal feed in the bacon hog ration.....	403
Biological method of detecting the presence of fungicides on seeds, A.....	458
Black rot of rutabagas.....	415
Book reviews.....	95, 161, 214, 461
Butter flavour, Acidity: Its relation to.....	137
<i>(Cephus cinctus</i> Nort.) on the Canadian prairies, A preliminary report on the climatology of the wheat stem sawfly.....	432
Cereal variety zone co-ordination in the Prairie Provinces, Report on.....	279
Chemical composition of feeding stuffs available in Canada, The.....	525
Cheese making: The retention of nutrients in.	
I. The retention of calcium phosphorus and riboflavin in cheddar cheese made from raw milk.....	817
II. The effect of pasteurization of the milk upon the retention of calcium, phosphorus and riboflavin in cheddar cheese.....	833
III. The calcium, phosphorus and riboflavin contents of cream, cottage, brick and blue cheese.....	845
Cherry, "Lambert mottle," a transmissible disease of sweet cherry.....	776
Codling moth control, Phenothiazine in.....	546
Common scab of potato in dry and wet soils.....	533
Contribution to the knowledge of the Acrididae of Alberta, A.....	577
<i>Cucurbitaceae</i> , <i>Fusarium sambucinum</i> Fkl. F. 6 Wr. as a pathogen of some species of the.....	537
<i>Cydia pomonella</i> L., in Southern France, Observations on the parasites of.....	1
Decimal system for the classification and mapping of Ontario soils, A.....	253
Détermination du magnésium échangeable dans les sols par la 8-hydroxyquinoléine.....	791
Diagnosis of sex by means of heteropycnosis, The.....	566
Digestibility of typical Eastern Canadian feeds by market bacon hogs, III, The.....	43
Disease of the European spruce sawfly, <i>Gilpinia hercyniae</i> (Htg.), and its place in natural control, A.....	65
Durum wheat grown in the durum wheat area of Western Canada, Agronomic and quality characteristics of Carleton.....	107

	Page
Effect of heat, insulation and artificial light on egg production and feed consumption of pullets, The.....	31
Effects of cultivation and cropping on the chemical composition of some Western Canada prairie province soils. Part III.....	718
Effects of subzero temperatures on <i>Hypoderma lineatum</i> DeVill, The.....	156
Egg drying, Further bacteriological studies relating to.....	551
Epidemiology of stem rust in Western Canada.....	285
Errata.....	462, 524, 738, 860
Feeding stuffs available in Canada, The chemical composition of.....	525
Feedstuffs, Riboflavin content of Canadian.....	542
Fifteen years experiments on the gray wooded soils of Alberta.....	626
Flax seed in Canada, Threshing-injury to.....	601
Frameworking fruit trees.....	163
Further bacteriological studies relating to egg drying.....	551
<i>Fusarium sambucinum</i> Fkl. F. 6 Wr. as a pathogen of some species of the <i>Cucurbitaceae</i>	537
<i>Gilpinia hercyniae</i> (Htg.), and its place in natural control, A disease of the European spruce sawfly.....	65
Growth of bacon type hogs. Rates of gain at specific live weights.....	854
(<i>Helianthus annuus</i> L.), Histological observations on the location of pigments in the akene wall of the sunflower.....	185
Histological observations on the location of pigments in the akene wall of the sunflower (<i>Helianthus annuus</i> L.).....	185
History, description, distribution and performance of Ajax and Exeter oats.....	96
Horses, The use of distillers', brewers' dried grains, and malt sprouts for.....	637
Hyacinths, Promising new methods used in propagation of.....	169
<i>Hypoderma lineatum</i> DeVill, The effects of subzero temperatures on.....	156
Identification of grain samples of hard red spring wheat varieties grown in Western Canada.....	711
Increase in production and value of the wheat crop in Manitoba and Eastern Saskatchewan as a result of the introduction of rust resistant wheat varieties.....	51
"Lambert mottle" a transmissible disease of sweet cherry.....	776
Legume and cereal sprouts as a dietary substitute for fresh vegetables.....	504
<i>Lygus hesperus</i> Knt. and <i>L. elisus</i> Van D. in Alberta, Number of generations of...	573
<i>Macrophomina Phaseoli</i> (Maubl.) Ashby in Ontario, Some studies on.....	690
Methyl bromide fumigation of plant products in railroad freight cars with special reference to work supervised by the Dominion Department of Agriculture during 1944.....	794
Milkweed survey in Ontario and adjacent Quebec, A.....	463
New lethargy in sheep. Nervous inco-ordination or paralysis at birth, A.....	482
Note on the production of vitamin C by sprouting seeds, A.....	499
Number of generations of <i>Lygus hesperus</i> Knt. and <i>L. elisus</i> Van D. in Alberta....	573
Oats, History, description, distribution and performance of Ajax and Exeter.....	96
Oats, Shattering in.....	426
Observations on the parasites of <i>Cydia pomonella</i> L., in Southern France.....	1

<i>Phasia</i> complex (Diptera, Tachinidae), A revision of the North American species of the.....	647
Phenothiazine in codling moth control.....	546
Physical factors affecting land use in a common soil type in Ontario.....	273
Pink rot disease of potatoes in British Columbia.....	597
Potatoes in British Columbia, Pink rot disease of.....	597
Potato in dry and wet soils, Common scab of.....	533
Preliminary report on the climatology of the wheat stem sawfly (<i>Cephus cinctus</i> Nort.) on the Canadian prairies, A.....	432
Promising new methods used in propagation of hyacinths.....	169
Pullets, The effect of heat, insulation and artificial light on egg production and feed consumption of.....	31
Revision of the North American species of the <i>Phasia</i> complex (Diptera, Tachinidae), A.....	647
Rapid soil tests on some Carleton County soil.....	231
Report on cereal variety zone co-ordination in the Prairie Provinces.....	279
Retention of nutrients in cheese making, The	
I. The retention of calcium, phosphorus and riboflavin in cheddar cheese made from raw milk.....	817
II. The effect of pasteurization of the milk upon the retention of calcium, phosphorus and riboflavin in cheddar cheese.....	833
III. The calcium, phosphorus and riboflavin contents of cream, cottage, brick and blue cheese.....	845
Review of the North American species of the genus <i>Argyrotaenia</i> Stephens (Lepidoptera, Tortricidae), A.....	81
Riboflavin content of Canadian feedstuffs.....	542
Rutabagas, Black rot of.....	415
Seed dispenser—device for measuring seed by volume for rod row plots, A.....	707
Seeds, A note on the production of vitamin C by sprouting.....	499
Seeds, A biological method of detecting the presence of fungicides on.....	458
Shattering in oats.....	426
Sheep, Nervous inco-ordination or paralysis at birth, A new lethal in.....	482
Soils in Alberta, Solonetz.....	780
Soil nitrates under various fertilization and green-manure cropping systems.....	179
Soil tests on some Carleton County soil, Rapid.....	231
Soil type in Ontario, Physical factors affecting land use in a common.....	273
Soils, Analysis of horticultural.....	175
Soils, A decimal system for the classification and mapping of Ontario.....	253
Soils, A study of the variability of certain chemical properties in.....	221
Soils of Alberta, Fifteen years experiments on the gray wooded.....	626
Soils. Part III, Effects of cultivation and cropping on the chemical composition of some Western Canada prairie province.....	718
Soils, The acid-oxalate extracts of podzol and podzolic.....	215
Solonetz soils in Alberta.....	780
Sols par la 8-hydroxyquinoléine, Détermination du magnésium échangeable dans les.....	791
Some factors affecting apple yields in Okanagan Valley.	
I. Tree size, tree vigour, biennial bearing, and distance of planting.....	189
II. Soil depth, moisture holding capacity, and pH.....	739
III. Root distribution.....	760
Some studies on <i>Macrophomina Phaseoli</i> (Maubl.) Ashby in Ontario.....	690
Stem rust in Western Canada, Epidemiology of.....	285
Studies on the optimum nutrition of flue-cured tobacco.....	489
Study of the variability of certain chemical properties in soils, A.....	221

	Page
Threshing-injury to flax seed in Canada.....	601
Tobacco, Studies on the optimum nutrition of flue-cured.....	489
Topography and minimum temperature.....	146
.	
Uniform method of analysis for square lattice experiments, A.....	115
Use of distillers', brewers' dried grains, and malt sprouts for horses, The.....	637
Wheat as the basal feed in the bacon hog ration, Barley vs.....	403
Wheat stem sawfly (<i>Cephus cinctus</i> Nort.) on the Canadian prairies, A preliminary report on the climatology of the.....	432
Wheat varieties grown in Western Canada, Identification of grain samples of hard red spring.....	711
Wheat varieties, Increase in production and value of the wheat crop in Manitoba and Eastern Saskatchewan as a result of the introduction of rust resistant....	51

AUTHOR INDEX

	Page		Page
Albright, W. D.....	146	Laidlaw, H. C.....	711
Andreae, W. A.....	504	Lajoie, P. G.....	215
Ashton, G. C.....	403, 854	Lajeune, A. J.....	711
Atkinson, H. J.....	231	Lott, T. B.....	776
Balch, R. E.....	65	MacGregor, H. I.....	31
Bell, J. M.....	43	Machacek, J. E.....	601
Berard, H. L.....	551	MacLean, A. J.	221
Bird, F. T.....	65	Marshall, J.....	546
Bird, S.....	31	Marshall, J. B.....	499
Bradt, O. A.....	179	McEvoy, E. T.....	489
Branion, H. D.....	525, 542	McFarlane, W. D.....	504
Brooks, A. R.....	647	Mead, H. W.....	458
Brown, A. L.....	718	Meredith, W. O. S.	107
Brown, A. M.....	601	Miller, J. J.....	690
Bryant, L. R.....	817, 833, 845	Monro, H. A. U.....	794
Cameron, C. D. T.....	854	Motzok, I.	525
Chalmers, Edith A.....	504	Newton, J. D.....	718
Chamberlain, G. C.....	680	Odynsky, Wm.....	780
Choinière, L.....	791	Patry, L. M.....	231
Craigie, J. H.....	51, 285	Peterson, R. F.....	107, 711
Crampton, E. W.....	43, 403, 637, 854	Pineau, M. A.	791
Crook, A.....	817, 833, 845	Pratt, Jean M.	31
Crossley, J. H.....	169	Putt, E. D.....	185
Delisle, R.....	794	Rasmussen, K.....	482
De Long, W. A.....	215	Richards, N. R.	273
Derick, R. A.....	426	Richardson, J. K.....	415
Dore, W. G.....	463	Ripley, P. O.....	231
Evans, E. V.....	542	Rock, P. J. G.....	577
Freeman, T. N.....	81	Salt, R. W.....	156, 573
Goodwin-Wilson, R.....	175	Sanford, G. B.....	533
Goulden, C. H.....	115, 707	Schmaltz, H. W.	525
Graham, W. D. M.....	525	Seamans, H. L.....	432
Groh, H.....	463	Simmonds, F. J.....	1
Gutteridge, H. S.....	31	Smith, Stanley G.	565
Hall, E. R.....	163	Sproule, W. H.....	817, 833, 845
Hamilton, D. G.....	426	Stoker, J. G.....	146
Hilderbrand, A. A.....	690	Summerby, R.....	221
Hill, D. C.....	525	Tyner, L. E.	537
Hills, G. A.....	253	Upshall, W. H.....	179
Hilton, S. A.....	854	VanHaarlem, J. R.	179
Irvine, O. R.....	817, 833, 845	Welsh, J. N.....	96
Jackson, S. H.....	817, 833, 845	White, A. H.	137
Johns, C. K.....	551	White, R. M.....	577
Johnson, L. P. V.....	499	Wilcox, J. C.....	189, 739, 760
Johnstone, W. M.....	817, 833, 845	Woods, J. J.	163
Jones, Walter.....	597	Wyatt, F. A.....	626, 718
Knight, A. T.....	760	Young, D. M.....	542
Koch, L. W.....	660	Young, G. A.....	499

OBSERVATIONS ON THE PARASITES OF *CYDIA POMONELLA* L. IN SOUTHERN FRANCE

F. J. SIMMONDS¹

Imperial Parasite Service, Belleville, Ontario

[Received for publication January 5, 1944]

INTRODUCTION

The codling moth, *Cydia pomonella* L., in Canada is an insect pest of major importance, particularly in the warmer parts of the country. Even though extensive and costly spraying programs are adopted, these do not seem to check the ravages of the pest, which threatens to make apple-growing unprofitable in large areas of Ontario. Hence it was decided to investigate the possibilities of the biological control of the codling moth in Canada by means of parasites imported from Europe, with the result that the present work was undertaken (Boyce (2)).

In 1928 and 1929 attempts had been made to obtain European parasites of the codling moth for introduction into New Zealand and South Africa, with a view to the biological control of the pest. Collections of hibernating larvae were made in France by Kozlovsky (Rosenberg (6)) in the autumn and winter of 1928 and 1929. The material was kept for emergence, and hosts and parasites reared out. Some of the parasites were bred in the laboratory, and shipments of one species, *Ascogaster quadridentatus* Wesm., were made to South Africa and New Zealand. The present work is, in many respects, a continuation and extension of Kozlovsky's and Rosenberg's work, and many references to, and comparisons with, the latter's paper will be made.

Site of Investigations

Kozlovsky made the greater part of his collections in Northwest France, though smaller collections were made elsewhere. In these districts apple-growing is an important industry, but infestation by the codling moth is not excessive, and parasitism was found to be very low (1.37% to 25.75%). Hence a great deal of host material had to be collected in order to obtain few parasites. It was, therefore, preferable to find a locality where parasitism was higher, even though the total number of hosts available might be less.

It was decided that the south of France would probably be a suitable locality for the investigations, although this is not an important apple-growing district. Here, in the Departments of Var and Alpes Maritimes, there are mountains which give, with change of altitude, highly varied climatic conditions. On the coast and in the lower parts of the river valleys the climate is subtropical, the summers are hot and dry, and the winters mild and wet. Higher up the mountains the climate becomes cooler, until

¹ Junior Entomologist.

at St. Martin-Vésubie (3,000 ft.), the highest locality investigated, the climate is sub-alpine. This great range of climatic conditions occurs in a comparatively small area.

With the varying conditions in this district it was hoped that a thorough investigation of the biology of the parasites of *Cydia pomonella* might be made, and that their distribution might be correlated with differences in climatic conditions. Such knowledge would be important when considering the introduction of parasite species for the control of *Cydia* in Canada, since ability to withstand adverse climatic conditions is a necessary characteristic of a parasite that is to be introduced. Hence the investigation was carried on chiefly in the Department of Var in the south of France, between Marseilles and the Italian frontier, though collections were also made near Rouen in Normandy for comparison with those made in the south of France.

Nature of Countryside

The coastal strip around Le Lavandou (Var) where laboratory headquarters were set up, is a fertile, and intensively cultivated region. The hinterland consists of cultivated valleys, and hills covered with xerophytic scrub, small pine trees, cork oaks, and *Quercus ilex* bushes. There is little succulent vegetation during the summer, since all that occurs in the spring is completely parched by July. In most places the farmers must irrigate many of their crops in the summer. The chief products are grapes, peaches, almonds, olives and figs. The farms are usually small, and much vegetable growing is done. Over most of the area there are few large orchards; the apple, pear, and quince trees are scattered, several to each small holding. This is a disadvantage in that large collections of *Cydia* material cannot be made from one place, but this is compensated for by the fact that these fruit crops are considered practically valueless, and are not given very effective insecticidal treatment, with the consequence that most of the fruit is attacked by *Cydia*.

There are one or two small areas where apples and pears are extensively grown, notably at Solliès Pont (Var) and the Vésubie valley (Alpes Maritimes). In the former locality the trees are systematically treated with arsenical sprays, etc., and *Cydia* infestations are, to a large extent, kept in check. In the Vésubie valley the change of climate with increasing altitude prevents serious *Cydia* outbreaks. Here, at St. Martin Vésubie, this sub-alpine climate is apparently too severe for *Cydia*, since no infested apples were found, though apples were plentiful. The climate here is hot in the day time during the short summer, cold at night, and very cold in the winter, when several feet of snow occur. From St. Martin Vésubie to the coastal strip there is a gradual transition to the sub-tropical climate. At Roquebillière (2,000 ft.) and La Lantosque (1,400 ft.) *Cydia* larvae were found, and samples taken; but it was only very much lower down, at Colomars and Nice, in the broad valley almost at sea level, that *Cydia* became common. Hence the distribution of *Cydia* itself in the region is considerably limited by climatic conditions, caused by differences in altitude.

During the summer months of 1939, samples of apples were taken from many localities. The apples were dissected to find young *Cydia* larvae, which in turn were dissected to determine percentages of parasitism, and

the parasite species present in these young stages of the host. Numbers of infested apples were also kept in order to rear adult parasites from the *Cydia* larvae.

Also during the summer a large number of fruit trees were banded with 6-inch wide corrugated cardboard bands to obtain hibernating *Cydia* material. Several hundred trees were also banded in Northwestern France near Rouen, where there are many large orchards. However, owing to the more temperate climate, *Cydia* infestations are low; about 15% of the fruit was attacked this summer, compared with 80 to 100% in the south of France. In many orchards careful insecticidal treatment is carried out, and *Cydia* has been eliminated as a serious pest. On the way back to Le Lavandou a number of walnut trees were banded near Grenoble (Isère).

During the latter half of August and September parasites were reared from the samples of maggoty fruit collected, and many hibernating larvae of *Cydia* and parasites were obtained, both from banded trees and by scutinizing the bark of unbanded trees.

Hibernating material thus collected was kept over winter and allowed to emerge in the following spring (1940). The life histories of the emerging parasites were investigated, but the work was brought to an abrupt close with the collapse of France in June 1940, when all material and the majority of the notes on the work had to be abandoned at Bordeaux. Because of this, many exact figures relevant to various aspects of the work have been lost, and allowance must be made for the comparative vagueness of some of the statements concerning the length of life history of parasite species, percentages of parasitism, etc., in those cases where the exact figures are unavailable.

DISSECTION OF YOUNG LARVAE

In order to investigate the distribution of parasites in the young larval stages of *Cydia*, samples of attacked apples were taken from many localities. The apples were carefully cut up and the *Cydia* larvae removed. These were then dissected, and the parasites contained in them noted. These were:—

Ascogaster quadridentatus, Wesm. This occurred as first stage larvae, never more than 1 in a host.

Pristomerus vulnerator Panz. Unhatched eggs and young first stage larvae were found. There were sometimes 2 in a host, and this species was found in hosts already containing an *Ascogaster* larva.

Perilampus tristis Mayr. Planidia of this species were found in unparasitised *Cydia* larvae, and also in association with *Ascogaster* and *pristomerus* larvae. As many as 8 were found in a single host larva.

The number of host larvae dissected and the parasites found are given in Table 1.

Of the hosts parasitised by *Perilampus*, 4 contained no other parasite. Since *Perilampus* larvae perish if alone in a primary host larva these 4 cannot be included in the number of hosts considered parasitised. Hence the number of hosts parasitised effectively is 112, not 116 as appears from the table; the total percentage parasitism is thus 37.5, not 38.8. Had

TABLE 1.—DISSECTIONS OF YOUNG LARVAE FOUND IN ATTACKED FRUIT

Locality	—	No. dissected	Unpara- sitised	<i>Asco- gaster</i>	<i>Prist- omerus</i>	<i>Peri- lampus</i>
6. Le Luc (Var)	14.vi. 39	46	30	18	—	—
7. Fréjus (Var)	19.vi. 39	2	1	—	—	1
8. Fréjus (Var)	19.vi. 39	23	10	12	—	4
8. Fréjus (Var)	19.vi. 39	25	11	13	—	2
9. Le Muy (Var)	19.vi. 39	11	10	—	—	—
11. Le Muy (Var)	19.vi. 39	27	20	7	—	—
12. Le Muy (Var)	19.vi. 39	20	12	6	2	—
12. Le Muy (Var)	19.vi. 39	23	15	8	—	—
13. La Farlede (Var)	23.vi. 39	44	27	15	3	—
14. Le Muy (Var)	24.vi. 39	6	3	3	1	—
15. Nice (A.M.)	28.vi. 39	17	9	4	3	2
16. Colomars (A.M.)	28.vi. 39	9	4	2	3	2
17. La Lantosque (A.M.)	28.vi. 39	9	5	4	1	—
20. La Lantosque (A.M.)	30.vi. 39	18	12	5	2	—
22. Le Lavandou (Var)	3.vii. 39	7	5	—	2	—
23. Ste. Maxime (Var)	6.vii. 39	12	9	1	2	—
Total		299	183	99	19	11
% Parasitism		—	61.2	33.1	6.4	3.7

the apples been left on the tree, the percentage would probably have been higher. The parasitism by *Ascogaster*, a species parasitising the host eggs, would not have increased, nor would that of *Perilampus*, whose planidia presumably enter the host larva before it burrows into the fruit. However, the host larvae would have been exposed to further attacks by *Pristomerus*, and the amount of parasitism by this species would have been greater.

In order to determine the stage of larva attacked by the three parasite species, records were kept of the head capsule size of each host dissected. These records show that all three species are present in the first stage *Cydia* larvae.

FRUIT ATTACKED

Cydia pomonella has been recorded from many different fruits: apple, pear, quince, peach, chestnut, walnut, etc., and it was thought possible that the parasite complex associated with hosts on different fruits might vary. The various species of fruit trees might have varying degrees of attraction for the adult parasites, or the availability of hosts to ovipositing parasites might differ.

In the early part of the summer apples were found to be the only fruit attacked by *Cydia* to any extent. A few pears were infested, but no larvae were found in quinces. Later, however, pears were more heavily attacked, although still less so than apples. In the autumn quinces suffered heavily, and nearly every fruit contained several larvae. The following figures show the number of larvae collected from banded quince trees compared with the number of fruit on each tree.

LOCALITY 37.—LA FAVIÈRE (VAR). BANDED 31. viii. 39.

BANDS AND TREES EXAMINED 22. ix. 39
and 21. x. 39

—	No. of fruit	Larvae
Tree 1	60	109
2	34	52
3	15	62
4	44	91
	153	314

Average—2.05 larvae per fruit.

This figure is no doubt too low, since all the larvae would not make their cocoons on the "host" tree; and even all those that did so would not be found.

Walnut trees were banded at Grenoble in a farm where *Cydia* larvae were found attacking the nuts. These bands, examined at the end of November, contained large numbers of hibernating larvae.

Almonds, plums, chestnuts, and peaches were also banded, but no *Cydia* larvae were obtained.

No difference was seen in the parasite complexes associated with different fruit except in two cases. Both specimens of *Ephialtes rugicollis* Desv. that were reared came from quince trees. The second case was shown by the material from the walnut trees mentioned above. From this material there emerged a larger proportion of *Cryptus sexannulatus* Grav. than was found in other collections, *Trichomma enecator* Rossi was also more common in this material.

PARASITES REARED FROM LARVAE IN FRUIT

Maggotty fruit was collected as above, but kept in large wooden boxes with gauze tops. The boxes were examined daily, and any fully fed larvae that had come out of the fruit were placed separately in glass tubes where there formed their cocoons. The emergents were then noted.

Parasites reared were:—

Ascogaster quadridentatus Wesm.

Pristomerus vulnerator Panz.

Trichomma enecator Rossi.

Hyperparasite:—

Perilampus tristis, Mayr (parasite of *Ascogaster* and *Pristomerus*).

The figures in Table 2 give the parasites emerging from larvae obtained in these collections.

TABLE 2.—EMERGENTS FROM *Cydia* MATERIAL COLLECTED FROM ATTACKED FRUIT

Locality	Date	Total larvae	Hibernating	<i>Cydia</i>	<i>Asco-gaster</i>	<i>Prist-omerus</i>	<i>Tri-chomma</i>	<i>Peri-lampus</i>
6. Le Luc (Var)	14. vi. 39	27	8	13	6	—	—	—
8. Fréjus (Var)	24. vi. 39	49	12	10	21	—	—	6
	11. vii. 39	260	112	96	24	7	—	21
12. Le Muy (Var)	24. vi. 39	18	1	15	2	—	—	—
	19. vi. 39	9	5	4	—	—	—	—
	9. vii. 39	96	49	41	4	—	—	2
	9. vii. 39	80	22	48	4	2	1	3
	21. vii. 39	35	23	12	—	—	—	—
15. Nice (A.M.)	27. vii. 39	48	43	1	1	2	—	1
16. Colomars (A.M.)	27. vii. 39	78	66	4	2	2	2	2
22. Le Lavandou (Var)	3. vii. 39	12	1	9	—	2	—	—
Total		712	342	253	64	15	3	35
% Total		—	48	35.6	9.0	2.1	0.4	4.9
% Emergents		—	—	68.4	17.3	4.1	0.8	9.5

Thus the total parasitism was 31.6%. Here, as in the dissections, the percentage of *Pristomerus* and also that of *Trichomma* is probably slightly less than that which would have occurred had the apples been left on the trees, exposed to further attacks by these two species. The individual species reared will be discussed below.

FIELD EXPERIMENTS

During the summer two experiments were carried out to investigate the following two points.

1. Does the severity of attack by *Cydia*, or the percentage of parasitism, differ at different points on a tree, or are both host and parasite ovipositions uniformly distributed? If large differences in this direction occurred, spraying with insecticides might be profitably regulated, so that heavily attacked parts of the tree received most treatment, while those where parasitism was high were untreated. In this way a given amount of insecticide would be used to the greatest advantage; and parasites, which otherwise would have been killed, would be allowed to emerge.

2. Does the variety of apple affect the amount of parasitism or percentage of larvae hibernating? Whether the variety affected the severity of the attack by *Cydia* was not investigated, but results from rearing experiments suggested that the percentage of larvae of the summer generations of *Cydia* that went into hibernation varied with the variety of apple tree.

In the case of the variation of parasitism in different parts of the tree only a single tree was investigated. The fruit was collected into 8 separate lots, from the 4 upper and 4 lower quadrants, the tree being "quartered" at the 4 points of the compass. The attack and emergents from each lot was noted. The southwest part of the tree was more heavily attacked by *Cydia* than the rest, and the *Cydia* larvae in the southeast lower part of the tree were more heavily parasitised than the remainder. Such an

experiment on a single tree is inconclusive evidence, but it is possible that more extensive investigation might indicate some differences in this direction, caused perhaps by such factors as the increased sunlight on the southern side of the tree.

From the experiments on two different varieties of apples, insufficient parasites were reared to see if there was a significant difference in parasitism between the two. There was, however, considerable difference (27.5% and 53.3%) between the numbers of larvae going into diapause rather than emerging (in midsummer) suggesting that the quality of larval food influences the tendency to go into diapause.

BANDING AND HIBERNATING MATERIAL

In order to collect a quantity of fully grown *Cydia* larvae and to investigate the parasites which attack the larvae within their cocoons, use was made of the familiar method of banding trees with corrugated cardboard. The bands used were about 6 inches in width and were placed as high as possible on the tree trunks, below the first branching. About 700 trees were banded; these were mostly apples, but there were also a number of pears, quinces, and walnuts, and a few plums, almonds and chestnuts. These bands were placed on the trees at varying times until the end of August, and were removed during September, October and November. At the same time as the bands were removed these and other trees were searched for hibernating larvae. The crevices in the trunks were carefully examined and the dead bark stripped off with a penknife.

With smooth barked trees such as young apples and quinces, the proportion of larvae which formed their cocoons in the cardboard bands was considerable; but when the bark was much fissured, as with old apple trees and pear trees, very few larvae were found in the bands, the majority having formed cocoons in the bark itself, showing the necessity of scraping rough barked trees prior to banding.

During this collecting, numbers of parasite cocoons (within *Cydia* cocoons) and insects that are possibly predaceous on hibernating *Cydia* larvae, were also found. These were kept and are discussed below.

The greater part of the material collected in this way remains as hibernating larvae until the following spring. However, a certain number of parasites emerged. These were:—

BRACONIDAE *Ascogaster quadridentatus*, Wesm.

ICHNEUMONIDAE *Pristomerus vulnerator* Panz.
 Trichomma enecator Rossi
 Ephialtes caudatus Ratz.
 Cryptus sexannulatus Grav.

CHALCIDIDAE *Dibrachys cavus* Walk.
 Dibrachys affinis Masi
 Melittobia acasta Walk.

Secondary parasites reared were:—

ICHNEUMONIDAE *Hemiteles*, 1.—From *Cryptus sexannulatus*.
 Hemiteles, 2.—From *Ephialtes* sp.

CHALCIDIDAE *Dibrachys cavus* Walk.—From *Cryptus*, *Ascogaster*, and *Pristomerus*.
 Perilampus tristis Mayr.—From *Ascogaster* and *Pristomerus*.

The hibernating material consisted of about 6,000 *Cydia* larvae and was obtained in two ways:

- (a) Individuals which went into hibernation from the collections of apples made in the early summer for rearing experiments.
- (b) From tree trunks and "banded" trees. In addition to this, 150 *Ephialtes* cocoons were collected, about 80 *Cryptus*, and a number of fully grown larvae of *Dibrachys* sp. Several unidentified parasite cocoons were also found. *Ascogaster* and *Pristomerus* were found overwintering as cocoons as well as in young larval stages within hibernating *Cydia* larvae.

As soon as the *Cydia* larvae were collected, they were placed with strips of corrugated cardboard, 1 inch wide and 5 corrugations broad, in which they formed their cocoons. These formed conveniently handled units.

A number of larvae collected were divided into two size groups, since some of them are very much smaller than others. These small larvae have been stated to be parasitised by *Ascogaster*, and it was hoped to see the difference in degree of parasitism between the groups when adults emerged.

All hibernating material was placed in an outhouse on a stone floor, and in February it was examined and placed in glass tubes or in cages suitable for emergence. As stated above much of the material had been separated into two parts, according to the size of the *Cydia* larva, and this distinction was still retained. The majority of the material was "forced" to provide earlier emergence, but some was kept under natural conditions in order to determine the normal times of emergence of the various species. These two categories will be dealt with separately. In both, percentage emergence varied with the conditions under which the hibernating larvae had been kept throughout the winter, and artificial hastening of emergence did not alter this. The best emergence was about 80%, when the larvae, spun up in corrugated strips, had been placed in metal gauze tins within cardboard containers and kept on a stone floor in an unheated outhouse.

Forcing

As has already been stated, it was decided, after successful trials, to force out the larger part of the hibernating material so that breeding experiments could be commenced. The material was removed from the boxes in which it had been kept over the winter and was placed in cages or jars kept in constant temperature boxes at 25° C. Each day emergents were removed and recorded. The sequence in which the parasites emerged was the same as that given below for unheated material, and emergence commenced at the beginning of March, about 6 weeks earlier than under natural conditions.

Table 4, drawn up from the few figures available, gives an idea of the percentages of parasitism, and the difference between the "large" and "small" hibernating larvae in this respect. The material was taken from quince trees growing in the hot coastal regions.

With the "small" *Cydia* larvae there were also a number of larvae of *Anarsia lineatella*, and some of the *Ascogaster* and *Pristomerus* may have emerged from this host. The scarcity of *Cydia* in the emergents does not indicate that only few *Cydia* larvae were present, but merely that the majority of these "small" larvae were parasitised. This was seen more clearly in other material. From this table it can clearly be seen that larvae parasitised by *Ascogaster* remain comparatively small before going into hibernation, and that only a very small percentage of these small larvae produce *Cydia* adults. The death rate of the "small" compared with the "large" is very high even though the two groups were kept under similar conditions. It is also evident that the *Cydia* larvae parasitised by *Pristomerus* tend to reach the normal size before hibernation occurs, although the "small" section contains 8.4% of this species in the emergents.

TABLE 4.—EMERGENTS FROM HIBERNATING MATERIAL

Locality	Size	No. of larvae	No. emerging	<i>Cydia</i>	<i>Anarsia</i>	<i>Ascogaster</i>	<i>Pristomerus</i>	<i>Perilampus</i>	<i>Parasitism</i>
1. Le Lavandou	Small larvae	254	53	1	3	36	7	6	—
			20.9*	1.9	3.7	67.9	13.2	11.4	92.5
2. Le May	Small larvae	100	21	—	11	9	1	—	—
			21.0	—	52.4	42.9	4.7	—	47.6
3. Le May	Small larvae	103	63	1	—	48	5	9	—
			61.3	1.6	—	76.2	8.0	14.3	98.4
4. Ste. Maxime	Small larvae	180	78	—	54	19	5	—	—
			43.3	—	69.2	24.4	6.4	—	30.8
Total		637	215	2	68	112	18	15	—
			33.7	0.9	31.6	52.1	8.4	7.0	67.5
5. Le Lavandou	Large larvae	70	39	35	—	—	4	—	—
			55.7	89.7	—	—	10.3	—	10.3
6. Le Lavandou	Large larvae	227	169	109	—	—	48	12	—
			74.4	64.5	—	—	28.4	7.1	35.5
7. Le Lavandou	Large larvae	575	474	402	—	—	62	10	—
			82.4	84.8	—	—	13.1	2.1	15.2
8. Le Muy	Large larvae	43	32	31	—	—	1	—	—
			74.4	97.0	—	—	3.0	—	3.0
Total		915	714	577	—	—	115	22	—
			78.4	80.8	—	—	16.1	3.1	19.2

* The second line in each case indicates percentage.

Natural Conditions

In order to obtain the normal times of emergence of both *Cydia* and its parasites under the conditions prevailing in the south of France, about 1,000 cocoons of the host and parasites were placed out of doors in cages contained in a large wooden box, closed and placed in the sun. A duplicate box was placed next to this, which contained a hygrothermograph for recording temperature and humidity. That this gave almost normal emergence times was confirmed by the observations in the field.

Hemiteles spp. emerged first, very much earlier than the rest. The remaining species of parasites, with the exceptions of *Ascogaster* and *Perilampus*, emerged well before *Cydia*. *Ascogaster* began to emerge somewhat after the host, and *Perilampus* was the last to emerge. This can be seen from Figure 1, giving dates of emergence (*Ascogaster* and *Perilampus* only approximate).

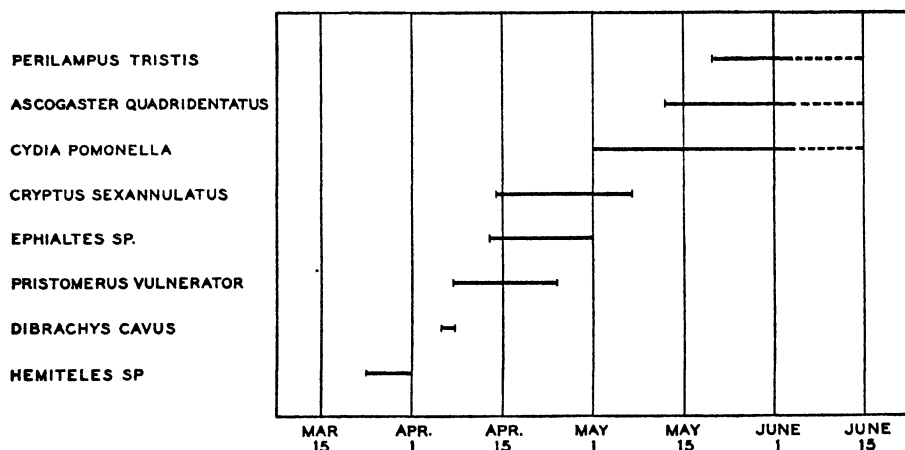


FIGURE 1.

TABLE 5.—ECTO-PARASITISM OF HIBERNATING *Cydia* LARVAE

Locality	Date	No. of <i>Cydia</i> larvae	<i>Ephialtes</i> cocoons	<i>Cryptus</i> cocoons	<i>Dibrachys</i>	Paralysed
11	4. xi. 39	150	29	5	2	5
12	4. xi. 39	350	5	—	3	—
15	13. xi. 39	101	—	3	—	1
16	13. xi. 39	20	—	1	—	1
20	13. xi. 39	73	3	5	—	3
23	26. xi. 39	460	7	4	11	8
24	20. x. 39	243	21	2	—	—
25	19. ix. 39	77	5	—	—	—
	18. x. 39	36	2	—	—	—
27	10. ix. 39	541	—	1	—	—
	23. xi. 39	156	—	18	—	2
35	13. xi. 39	245	1	8	—	3
36	13. xi. 39	59	5	1	—	1
37	16. ix. 39	147	3	—	—	1
	18. x. 39	51	1	—	—	—
	22. x. 39	227	14	3	1	—
38	3. ix. 39	160	—	—	—	—
39	15. x. 39	60	—	—	—	2
40	17. x. 39	23	1	—	—	—
41	18. x. 39	11	1	—	—	2
42	18. x. 39	55	—	—	—	2
43	19. x. 39	243	2	3	—	1
44	22. xi. 39	104	1	—	—	4
45	23. x. 39	9	3	—	—	1
46	24. x. 39	148	4	5	—	9
47	25. x. 39	137	7	—	—	—
		15	1	—	—	—
		25	1	—	—	—
48	25. x. 39	64	1	1	—	—
49	4. xi. 39	11	—	—	—	—
		3990	118 2.8%	60 1.4%	17 0.4%	46 1.1%

Total number attacked by parasites: 241 = 5.7%.

Ectoparasites in Hibernating Material

An indication of the percentage parasitism by ecto-parasites of the hibernating *Cydia* larvae in their cocoons is given in Table 5. This shows the number of parasite cocoons and larvae collected, at the same time as the collections of hibernating *Cydia* larvae were made. Owing to the fact that parasites may be on the wing and ovipositing in the autumn after the collections were made, and that, as is seen in the diagram, they emerge (or start ovipositing) before *Cydia* emerges in the spring; the figures in Table 5 are certainly lower than the real percentage parasitism achieved by these species.

No significant difference is seen between the percentage parasitism of *Cydia* larvae taken from apples, pears, or quinces. From those taken from bands on walnut trees, the same parasite species were obtained but the percentage of *Trichomma* and *Cryptus* was much higher. Also no difference was noted due to varying locality, or to climatic variation in the mountains. Hibernating larvae from North France were so few as to give no results.

List of Parasites Emerging from Hibernating Material

PRIMARY PARASITES

ICHNEUMONIDAE:

<i>Pristomerus vulnerator</i> Panz.	Endoparasitic within <i>Cydia</i> larva.
<i>Trichomma enecator</i> Rossi	Endoparasitic within <i>Cydia</i> larva.
<i>Ephialtes caudatus</i> Ratz.	Ectoparasitic on <i>Cydia</i> larva in cocoon.
<i>E. crassiseta</i> Thoms.	Ectoparasitic on <i>Cydia</i> larva in cocoon.
<i>E. ruficollis</i> Desv.	Ectoparasitic on <i>Cydia</i> larva in cocoon.
<i>E. cydiae</i> Perk.	Ectoparasitic on <i>Cydia</i> larva in cocoon.
<i>Cryptus sexannulatus</i> Grav.	Ectoparasitic on <i>Cydia</i> larva in cocoon.

BRACONIDAE:

<i>Ascogaster quadridentatus</i> Wesm.	Endoparasitic on <i>Cydia</i> larva.
<i>Meteorus(?)chrysophthalmus</i> Nees	Endoparasitic on <i>Cydia</i> larva.

CHALCIDIDAE:

<i>Dibrachys affinis</i> Masi	Endoparasitic in <i>Cydia</i> pupae.
<i>D. cavus</i> Walk.	Ectoparasitic on <i>Cydia</i> larvae.

TACHINIDAE:

<i>Arrhinomyia tragica</i> Mg.	Endoparasitic in <i>Cydia</i> larva.
--------------------------------	--------------------------------------

SECONDARY PARASITES

ICHNEUMONIDAE:

<i>Hemiteles</i> spp.	Parasitic on <i>Ephialtes</i> , <i>Cryptus</i> , and <i>Pristomerus</i> cocoons.
-----------------------	--

CHALCIDIDAE:

<i>Perilampus tristis</i> Mayr.	Parasitic on <i>Pristomerus</i> , <i>Cryptus</i> and <i>Ascogaster</i> .
<i>Dibrachys cavus</i> Walk.	Parasitic on <i>Pristomerus</i> , <i>Ephialtes</i> , <i>Cryptus</i> and <i>Ascogaster</i> cocoons.

The list contains only species which are definitely known to have emerged from *Cydia pomonella* L. Besides the above there were 2 further unidentified species of Ichneumonidae and 2 Chalcididae, single specimens of which emerged from the *Cydia* material.

With the emergents from hibernating material experiments on the length of life of the adult parasites and the life histories of the species were started, and will be dealt with under each species separately.

PREDATORS AND DISEASE

In the "bands" and under the bark of trees examined for hibernating *Cydia* larvae, numbers of possible *Cydia* predators were taken; these included: *Tenebrioides mauritanicus* L. (TEMNOCHILIDAE); *Dolichosoma lineare* Rossi (MELYRIDAE); *Cantharis* (? *rustica* Fall.) (CANTHARIDAE); *Malachius* (? *bipustulatus* L.) (MELYRIDAE); *Mecynstarsus* (? *serricornis* Panz.) (ANTHICIDAE).

All of these are Coleoptera. Raphidiid larvae, Geophilids, and the mite *Pediculoides ventricosus*, Newp., are also possible predators.

These predators were all tested in the laboratory with *Cydia* cocoons, but in no case were the experiments successful, and the value of insect predators in the control of *Cydia* in the south of France would appear to be negligible.

In many places the "bands" were attacked by birds, the larvae being removed from their cocoons through holes in the cardboard. Lizards have been found under the "bands," and no doubt they destroy a number of larvae descending the tree trunk to form their cocoons.

Many larvae in the cocoons were found attacked by fungus and polyhedral disease, which must decrease the numbers of hibernating larvae considerably in some seasons.

NOTES ON PARASITES REARED

Host

Cydia pomonella L.

From forced material the host species began to emerge in the middle of March, from material under natural conditions on 1st May, and was seen in the field a few days later. For breeding experiments with some of the species young larvae were required, and from the middle of March onwards *Cydia* breeding cages were set up under conditions generally supposed to be favourable to the species, 25° to 30° C., and high humidity. Many types of containers were tried, but it was only after some time that a reasonable supply of eggs was obtained, in glass jars kept in the dark at 30° C. No experiments were done on the life history of *Cydia*, the main point of interest being the time of emergence—from 1st May onwards, and the number of generations annually. The second generation was found (in 1939) to emerge from the beginning of July onwards, and individuals which may belong to a partial third generation emerged in September.

PRIMARY PARASITES

Pristomerus vulnerator Panz. (Ichneumonidae, Ophioninae)

A full host list is given by Rosenberg (6) who makes the suggestion, also indicated here, that the species also parasitises *Anarsia lineatella* Zell. *Pristomerus* apparently occurs throughout Europe, and is found also in Japan.

This species was present in material from all localities investigated, and occurred to the extent of just under 40% in one collection of larvae made from quince trees in the Var. The average percentage was about 10 to 20. *Pristomerus* began to emerge on 7th April and continued to do so until the 24th of this month; the sexes were about equal (about 200 individuals), and the males emerged somewhat before the females. As *Pristomerus* parasitises very young *Cydia* larvae, there would thus be a period of about a month between the earliest emergence of the parasite and the presence of larvae suitable for parasitism. Eggs were found in dissected hosts in the middle of June and adults emerged:—

July 24 1	25	26	27	28	29	30	31	August 1 2 3 4 5 6					
August 7 1	8	9	10	11	12	13	14	15	16 1	17 1	18 2	19 1	
August 20 1	21 1	22 1	23	24 1	September 12 1								

A female was also seen on 30th September ovipositing. Thus there appear to be two generations during the year with a possible partial third in the late autumn.

On emergence in the early spring adults were placed in breeding cages to determine the length of life. They were supplied with honey-water and raisins.

There were three different set-ups:—

1. Adults from material placed at 25° C. to hasten emergence—in small cage.
2. Adults from material emerging under natural conditions:
 - a. In small cage;
 - b. In large cage (1 cubic metre).

Between 1 and 2a there was little difference in length of life. There was, however, a great difference in coloration, those from heated material were lightly coloured, with a predominance of red markings and little black coloration; those emerging under natural conditions were, on the other hand, very darkly marked, had little red coloration, and had a greenish sheen.

There was also a striking difference in longevity between adults kept in small cages and those in the large one. Those in the latter cage were much shorter lived than the others; this perhaps was due to their greater opportunity for flying, and hence greater consumption of energy. In all cases males were slightly shorter-lived than females.

In no case was mating observed. However, for breeding experiments females were removed from a cage where about 50 individuals of each sex had been together for some time. These females were placed 5 at a time with 50 young *Cydia* larvae in suitable cages. These cages were 40 cm. in length, 20 cm. wide, and 12 cm. high. The floor and back were made of wood, the two sides of very fine iron-wire gauze, and the top was of glass, let into the wooden framework of the cage, and which could easily be lifted out by turning the fasteners which held it in place. The front was of wood, hinged at the base to act as a door, and in the centre of this was bored a large hole fitted with a cork through which insects could be introduced or removed.

Fitting into these cages, but leaving sufficient room for a jar of honey-water and some raisins, were pieces of wood 2.5 cm. thick, which had 50 holes, 1.5 cm. deep bored in the upper side. Into these holes glass tubes fitted tightly. For oviposition experiments these tubes were prepared as follows.

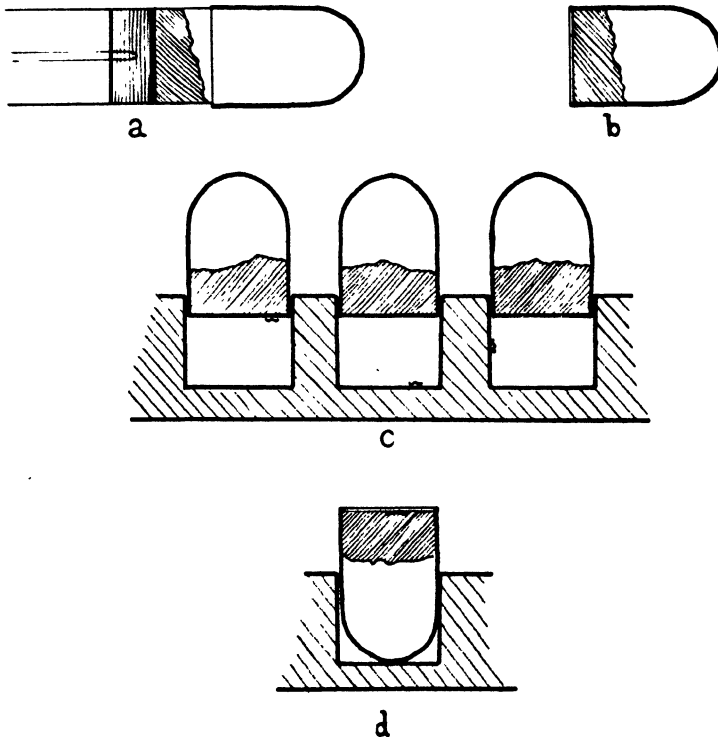


FIGURE 2. Diagrams showing *Cydia* larvae in apple plugs used for *Pristomerus* propagation:—

- (a) Cork-borer containing a plug of apple, piston pushing the apple into a glass tube.
- (b) Glass tube with apple plug inserted, skin of apple flush with edges of tube and fitting tightly.
- (c) Tubes prepared as (b) inverted over holes of the same diameter in wooden block. Single *Cydia* larvae which have just hatched have been confined in these spaces, when they bore into the apple plugs.
- (d) After 24 hours tube is inverted in hole, now with *Cydia* larvae just below skin, and ready for parasitisation experiments.

By means of a cork-borer and well-fitting plunger pieces of apple of the same diameter as the glass tubes were inserted into the mouths of the latter so that the apple skin was flush with the edge of the glass (see Figure 2). Freshly emerged *Cydia* larvae were then placed with a brush onto the apple skin, one to each tube, and the tube inverted in one of the holes in the wooden tray (see diagrams). The *Cydia* larva could wander in the air space and eventually bored into the apple plug. After being left for a day to enable the larvae to bore into the apple, the tubes were inverted and placed in the holes with the apple skin exposed (as in Figure 2).

Trays of tubes thus prepared were placed in the cages with the *Pristomerus* females, which showed great interest in the apple plugs and immediately commenced exploring the apple surface with their antennae. Great interest was shown when the antennae reached the holes by which the *Cydia* larvae had bored into the apple, and when they were over frass or other traces of the larvae. When some trace of a host larva was found the female excitedly thrust the ovipositor into the apple or larval tunnel, sometimes inserting the whole abdomen into the latter in an attempt to reach the larva.

In the first trials females were left with smaller trays of larvae for 24 hours or more, after which the larvae were removed from the apple plugs and dissected. In one of these 10 male and 10 female *Pristomerus* were left for two days with 40 prepared apple plugs and then these were examined. Thirty-four larvae were found, the other 6 having presumably wandered off the plugs. These were dissected and contained:—

No. of parasite eggs	0	1	2	3	4	5	6	24	27
No. of <i>Cydia</i> larvae	19	6	1	3	—	2	1	1	1

Thus 84 eggs were laid and 15 out of 34 hosts parasitised.

Unfortunately these are the only exact figures available, but this shows that about 3 eggs were laid per female per diem. In similar experiments superparasitism was always great, and the egg distribution was such that fewer hosts were parasitised than would have been expected from a random distribution of eggs. This was caused by the fact, as seen above, that individual larvae sometimes receive a very large number of eggs. The two larvae which received 24 and 27 eggs in the experiment above were completely choked with parasite eggs, and were moribund. This superparasitism was due to the differing availability of the *Cydia* larvae. Some tunnelled deeply into the apple plug and were completely immune from attack by the parasites; others, having only tunnelled shallowly, were soon heavily parasitised and stung to immobility.

To avoid this the apple plugs were then made thinner (.5 cm.) so that larvae could not become immune by burrowing deeply into the plug. Dissections showed less superparasitism by the ovipositing females. In larvae collected in the field 2 or 3 *Pristomerus* eggs were sometimes found, but no heavy superparasitism was noted.

After being exposed to ovipositing females the apple-plug trays were removed and the larvae dissected out of the apple. Parasitised larvae could be distinguished by the easily visible black parasite eggs. These larvae were then placed with apples in boxes for the further development

of the *Cydia* larvae and their contained parasites. Several hundred parasitised larvae, placed on apples in this way were being reared. The life history was found to agree with the description given by Rosenberg (1934).

In 1939 the first emergence record for *Pristomerus* was 24th July, and the spring generation began to emerge on 7th April, 1940. Hence the life-cycle is about $3\frac{1}{2}$ months to the summer generation, including 3 to 4 weeks after emergence as a pre-oviposition period before suitable hosts are available. A single specimen emerged in September, 1939, and several others between this month and March, 1940, from hibernating material. Hence, in the south of France, there are two generations of *Pristomerus*, with a few odd individuals emerging during the winter.

The stages in which the insect hibernates are interesting. Hibernation occurred most commonly in the young larval stage, probably the first stage, within the host. Several such larvae were found in dissections of hibernating *Cydia* larvae. The larvae feed up quickly in the spring, discard the empty host skins, and spin their cocoons. This occurs about a fortnight before the pupation of unparasitised *Cydia* material, and gives a simple method of separating material parasitised by *Pristomerus* from the remainder. Although this is the most usual stage for hibernation, throughout the winter there have been found in the field in the south of France *Pristomerus* cocoons from which adults have emerged in the spring. Also from a cocoon taken from a quince tree on 18th October, 1939, there emerged, on 16th November, a female *Pristomerus* which hibernated as an adult, and lived 144 days until 18th April, 1940. Hence this species can overwinter in several stages.

It was found to be parasitised in the cocoon by:—

Hemiteles sp.

Dibrachys cavus Walk.

D. affinis Masi (only in laboratory experiments);

and in the larval stage by:—

Perilampus tristis Mayr.

Trichomma enecator Rossi (*Ichneumonidae*, *Ophioninae*)

A full host list is given by Rosenberg (6), in addition to which it was reared from pine shoot moth (*Rhyacionia buoliana* Schiff.) material taken in the south of France in 1940.

This species was much rarer than *Pristomerus*, and was found in *Cydia* material from apples, pears, and quinces. Here it constituted about 1% of the emergents. It also emerged from a pupa of *Rhyacionia buoliana*.

Emergence from "forced" material occurred at the same time as, or slightly before, that of *Pristomerus*. Only 5 males emerged out of a total of about 20 individuals. At room temperature both sexes lived for about 5 weeks, and, as with *Pristomerus*, there is an enforced pre-oviposition period before suitable hosts are available.

Copulation was observed several times, in all cases some days after emergence. There was no preliminary courtship before mating; the males flying in the cage suddenly alighted on the females' backs, and copulation occurred immediately, lasting for about an hour.

For oviposition females were placed in cages prepared as for *Pristomerus*, with day-old *Cydia* larvae in the apple plugs, whole apples containing larvae being also present. As in the case of *Pristomerus*, all traces of the larvae were carefully examined with the antennae, and attempts were made to parasitise the young larvae. The abdomen was considerably arched so as to bring the short ovipositor under the head whence it was thrust into the hole left by the *Cydia* larva on entering the apple. The short ovipositor is supplemented by the long abdomen, which is thrust into the larval tunnels in the excited efforts of the female to sting the host. Several larvae were dissected but no eggs or parasite larvae were found. Unfortunately the subsequent development could not be investigated owing to the international stitution.

This was recorded only three times from *Cydia* material collected while still in the fruit, and emerged on 14th and 20th August and at the end of September. Thus there are two generations of this species.

Ephialtes spp.

Species of this genus reared from *Cydia* material by Rosenberg were identified as *Ephialtes extensor* Taschb. Subsequent re-examination of the specimens showed that there were two distinct species present. *E. caudatus* Ratz., and *E. crassiseta* Thoms. (see Perkins (4)), but no *E. extensor* Taschb.

From hibernating material both these species were reared, together with *Ephialtes* sp. nov. since described by Perkins (5) as *E. cydiae*, and an unidentified species, which, from correspondence with Perkins, seems likely to be *E. ruficollis*, Desv. The comparative numbers of the species in the material may be judged from Table 3, which gives those *Ephialtes* emerging from a part of the hibernating cocoons.

TABLE 3.—EMERGENTS FROM ECTO-PARASITE COCOONS

<i>E. caudatus</i>	<i>E. crassiseta</i>	<i>E. ruficollis</i>	<i>E. cydiae</i>	<i>Cryptus</i>	<i>Hemiteles</i> (ex <i>Cryptus</i>)
32 (17 ♂ 15 ♀)	2 (2 ♀)	2 (2 ♀)	5 (5 ♀)	27 (5 ♂ 22 ♀)	20 (♂ 14 ♂)

From this it is seen that by far the most common *Ephialtes* species was *E. caudatus* Ratz. Collections of adults on the wing in the autumn showed that *Ephialtes cydiae* Perk. is also common. The other two species must be considered rare.

Ephialtes spp. were found on apples, pears, and quinces, but not on walnuts. However, more extended collections would probably have found them here. *E. ruficollis* Desv. was found only on quince. The percentage occurrence of *Ephialtes* is seen in Table 4, where, owing to the impossibility of separating the larvae of the species without microscopic examination, all species are placed together. In the diagram giving times of emergence (Figure 1), they have also been placed together, as they emerge at about the same time, the latter half of April.

Attempts were made to breed all four species, and the results are given below under each species separately.

Ephialtes caudatus Ratz. As for the following species, exact figures for the length of adult life are not available, nor are the exact number of eggs laid per female. However, *E. caudatus* was found to have a length of life in agreement with that given by Rosenberg for *E. "extensor,"* i.e. males about 4 to 5 weeks, females about 7 weeks. Copulation was observed many times, and females mated immediately on emergence from the cocoon (cf. Rosenberg). A pre-oviposition period of about a week to a fortnight followed this.

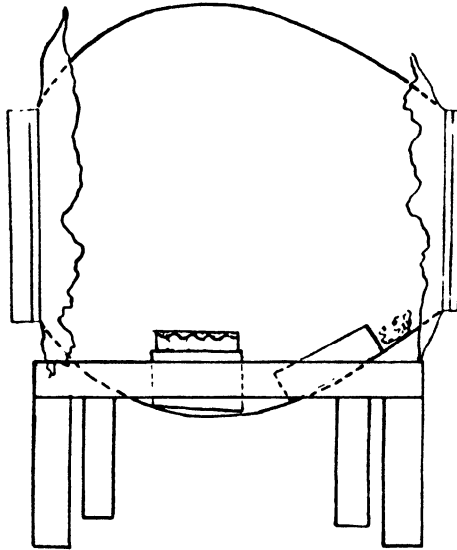


FIGURE 3. Oviposition cage used for breeding *Ephialtes* and *Cryptus* showing muslin ends to the glass cylinder, honey-water dish, and *Cydia* cocoons.

After mating, females were isolated in cages for oviposition (see Figure 3). These cages were glass shades for oil-lamps with both ends covered with muslin; they contained dishes of honey-water and raisins and also 10 *Cydia* larvae hibernating in cocoons made in strips of corrugated cardboard. These latter were placed in a small cardboard "pill-box" and arranged so that they were available for parasitisation. Each day the cocoons were examined, and those which had been parasitised were replaced, the number of eggs laid being recorded. Stinging and paralysis of larvae occurred for some days before actual oviposition took place. The acts of stinging and oviposition were as described by Rosenberg for *E. "extensor;"* the number of eggs laid, and presence of collapsed eggs, was also in agreement with his figures. Throughout the oviposition period eggs were laid steadily at the rate of 2 to 3 per diem. Then, after a few days in which no eggs were laid, the females died. Great variation occurred in both the length of life and number of eggs laid per female. Also during oviposition the ovipositors of several females were snapped off, either accidentally broken whilst egg-laying, or else bitten off by the struggling *Cydia* larva.

Superparasitism frequently occurred, no apparent discrimination between healthy and parasitised larvae being shown. Two or more eggs were even laid during single attacks. In these cases, the first larva to hatch destroys the other eggs, or else the stronger larva kills the other larvae during the first stage, and only one develops per host. Development at 25° C. was the same as that given by Rosenberg for *E. "extensor"*; i.e. egg stage about 1 day, 6 days for the 5 larval stages until cocoon formation, 2 days forming the cocoon, and then 12 to 13 days until emergence; in all about 3 weeks for full developmental time.

E. crassiseta Thoms. Only a few individuals of this species were reared and only 3 jars set up as above. Oviposition was poor, and the length of life less than in the preceding species. Development was similar to that of *E. caudatus* Ratz., as far as it was studied, although the life cycle was not completed. In one case this species was found in the field parasitic on an *Ephialtes* larva. The "hyperparasite" was reared, and a female emerged which had developed on a larva of its own genus.

Ephialtes ruficollis Desv. Only 2 females of this species were obtained from *Cydia* cocoons on quince trees. These females were unmated, lived about 4 weeks in the oviposition jars, and died without laying.

Ephialtes cydiae Perk. Emergence of this species occurred somewhat earlier than that of the other species of *Ephialtes*. Only 2 males emerged out of about 25 individuals. Mating was observed, but only some days after emergence. However, on 6th June, 1939, numerous males of this species were seen flying round an apple tree at Aubord (Gard), presumably waiting for the emergence of females from their cocoons. These males were undoubtedly the parthenogenetic progeny of females which emerged earlier in the spring.

Eight jars were set up as before for oviposition. There was a pre-oviposition period as in *E. caudatus* Ratz., length of life was similar, and there was a period at the end of the life of the female when no eggs were laid. Fewer eggs were laid by this species than by *E. caudatus* Ratz., but this may be due to the possible unmated condition of the females. Superparasitism and development were similar to those in *E. caudatus* Ratz.

A comparative study of the various stages of the species of *Ephialtes* was started, and drawings made where possible (not of *E. ruficollis* Desv.). The egg of *Ephialtes cydiae* Perk. differed from those of *E. crassiseta* Thoms. and *E. caudatus* Ratz. which were indistinguishable. Head capsules of freshly emerged larvae were different in the three species, as were the heads of the full-grown larvae, particularly as regards the labial ring. As far as could be followed, the development of the three species was similar.

All the species emerge in the spring some three weeks before their host. In the field oviposition was observed in April, the spring generation of *Ephialtes* attacking the hibernating *Cydia* cocoons. Owing to the long life of the female parasite the spring generation is also able to attack the first generation of *Cydia* larvae in early June, which generation is also attacked by the progeny of the earlier emergents of the *Ephialtes* spring generation.

There is, therefore, considerable overlap in the parasite generations. What occurs during the summer is as yet unknown, but presumably

parasites attack the first generation cocoons, and also the hibernating cocoons in August. Adults have been seen ovipositing from September to December, 1939. The winter may be passed as the young or fully-grown larva; and in *Ephialtes cydiae* possibly as the adult, since adults were seen flying in November, and although many of this species were on the wing in the autumn, the percentage emerging from hibernating material was small. Some of the hibernating larvae seem to be in a diapause, which cannot be broken by rise in temperature; however, the majority are not so, and rise in temperature causes development to proceed normally; hibernation in this case is due only to the fact that the temperature is insufficient for development, which is usually arrested in the late larval stage.

Species attacking *Ephialtes* cocoons were:

Hemiteles sp.

Ephialtes crassiseta Thoms.

Dibrachys cavus Walk.

Cryptus sexannulatus Grav. (*Ichneumonidae*, *Cryptinae*)

This species was quite common in hibernating material. Males were few, as is seen in Table 3. Cocoons were found on trees of all the fruits bearing the host. Emergence occurred at the same time as *Ephialtes*, that is, about 3 weeks before *Cydia*; under natural conditions emergences started on 13th April, 1940 (*Cydia*, 1st May).

Females were placed in jars for oviposition, set up as for *Ephialtes*. A pre-oviposition period of about 10 days occurred, during which host larvae were paralysed but no eggs laid on them. After this eggs were laid regularly, at the rate of 3 to 4 per diem, until 50 to 60 (maximum) had been deposited, superparasitism occurring as with *Ephialtes*. Following this there was usually a period in which no eggs were laid, and the female died. From the first females only male progeny was reared. At 25° C. the egg stage lasts about 2 days, the larval period before cocoon formation about 6 days, and males emerged some two weeks after this. Thus the life cycle is about 3 weeks. Males thus bred were placed with females and copulation was frequently observed, but no adult progeny was obtained from these females, owing to the cessation of the work. The length of life of the female was over 7 weeks, the average of that of the males 4 to 5 weeks.

It would seem that females emerging in the spring oviposit on hibernating *Cydia* larvae, giving rise to progeny consisting predominantly of males; these then fertilise the original females to produce a later bisexual generation. As with *Ephialtes*, the course of generations during the summer is unknown, but it is highly probable that the species can parasitise *Cydia* larvae throughout this period. The autumn generation gives rise to larvae which hibernate when fully-grown.

In the oviposition jars, *Cryptus* stung and oviposited on pupae as well as larvae of *Cydia*. The larvae hatching from eggs thus laid, started feeding at intersegmental joints, where the cuticle was thin. Many of these larvae did not complete their development, but a few managed to do so. This clears up a point mentioned by Rosenberg who was puzzled at finding a *Cryptus* cocoon associated with *Cydia* pupal remains.

Species found parasitising *Cryptus* cocoons were:

Hemiteles hemipterus F.

Hemiteles sp.

Dibrachys cavus Walk.

Perilampus tristis Mayr.

Ascogaster quadridentatus Wesm. (*Braconidae*, *Cryptogastrinae*)

A full host list is given by Rosenberg (6).

This was a common species in the hibernating material from all fruits, and, as shown in Table 4, the parasite larvae have the effect of arresting the development of the *Cydia* larvae before they reach their maximum size. Hence in hibernating material the percentage of parasitism by this species is much higher amongst the small larvae than amongst the large.

This species emerged at the same time or somewhat after the main body of *Cydia*, about mid-May. The length of life was determined, but apart from this no work was done on *Ascogaster*.

This was the most common parasite found in the young larvae of *Cydia*, and it was found in all localities investigated. In young larvae from fruit, the percentage parasitised was much greater than that found by Rosenberg in hibernating *Cydia* larvae.

The first generation of *Ascogaster* emerges before June and emergents recorded were:

July												
11	12	13	14	15	16	17	18	19	20	21	23	23
1♂	—	1♀	1♀	3♀	4♀	3♂ 2♀	1♂ 2♀	3♂ 2♀	1♂ 1♀	—	3♀	—
August												
24	25	26	27	28	28	30	31	1	2	3	4	5
3♀	—	—	1♀	—	—	—	2♀	—	4♂ 2♀	2♂ 1♀	1♂	—
7	8	9	10	11	12	13	14	15	16	17	18	19
—	1♂	1♂	—	2♂	1♂	—	1♂ 1♀	3♀	1♀	2♀	1♂	1♂
20	21											
—	2♂											
November												
22	27											
1♂	1♀											

It seems that there are three generations with a partial fourth. The very late emergents may hibernate over winter, since unless there are alternate hosts available, it is difficult to see where oviposition could occur.

Parasites:

Dibrachys cavus Walk.

Perilampus tristis Mayr.

Meteorus? chrysophthalmus Nees (*Braconidae*, *Polymorphinae*)

As before, Rosenberg (6) gives a full host list of this species.

Specimens of a primary parasite of *Cydia*, thought to be this species, emerged from material from several localities, particularly from that from walnut trees at Grenoble. Emergence occurred at the same time as *Ascogaster*. There were only a few individuals and no mating was observed; and, although supplied with *Cydia* larvae in various stages, females made no attempt to parasitise them.

Arrhinomyia tragica Mg. (*Tachinidae*)

Only 3 specimens of this species were obtained from thousands of hibernating larvae. These were supplied with *Cydia* eggs and young larvae, but no parasitism occurred; fully-grown larvae were also supplied, without success. Owing to the small number of adult parasites available, attempts to breed them were discontinued. It seems possible that the species may attack fully-grown larvae when they leave the fruit to form their cocoons, although microtype eggs are laid, of the type usually laid on the food and ingested by the larvae.

SECONDARY PARASITES

The following species were reared from *Cydia* material, but were secondaries, or at the most only occasionally primarily parasitic on *Cydia*.

Hemiteles spp. (*Ichneumonidae*, *Cryptinae*)

There were at least three species of *Hemiteles* bred from *Cydia* cocoons, and these included alate and brachypterous forms; the systematics of the group are, however, greatly confused, and exact determinations of the species are difficult.

Hemiteles spp. were reared from:

Pristomerus vulnerator Panz.

Ephialtes sp.

Cryptus sexannulatus Grav.

Rosenberg (6) gives the host list of *H. hemipterus* F. and deals briefly with the life history of this species, and also that of *H. macrurus* Ths. *Hemiteles* spp. were found naturally only as secondary parasites, but 1 adult was reared through from an egg which had been laid on a *Cydia* larva, on which larvae oviposition readily occurred in the laboratory. It seems possible that, under natural conditions, a number of *Cydia* larvae are paralysed and killed by these parasites.

By far the greater number of *Hemiteles* emerged from *Cryptus* cocoons, and from Table 3 it is seen that from part of the *Cydia* material emerged 5 males and 22 females *Cryptus* and 6 males and 14 females *Hemiteles*—i.e. 42.5% parasitism of *Cryptus*. Only in one case did the species emerge from a *Pristomerus* cocoon.

Emergence occurred long in advance of all other species, commencing on 23rd March, 1940. The species are long lived, and can therefore attack a large number of hibernating parasite larvae before these metamorphose in the spring. Even without this spring attack it is seen that 42.5% of the *Cryptus* cocoons are parasitised. Hence, in the absence of *Hemiteles*, the control of *Cydia* by *Cryptus* would perhaps be greater.

Perilampus tristis Mayr. (*Chalcidae*, *Perilampidae*)

Perilampids reared by Rosenberg (6) from *Cydia* material were identified as *P. tristis* Mayr. and *P. laevifrons* Dalm. He did not investigate the life-history of the species. Subsequent examination of the same material showed that only one species, *P. tristis* Mayr., was present, and all the material reared in this work belongs to the same species. Planidia

(Figure 4) were found in the young *Cydia* larvae dissected in the early summer. They were found in otherwise unparasitised *Cydia* larvae, and also in host larvae already parasitised by *Ascogaster* and *Pristomerus*.

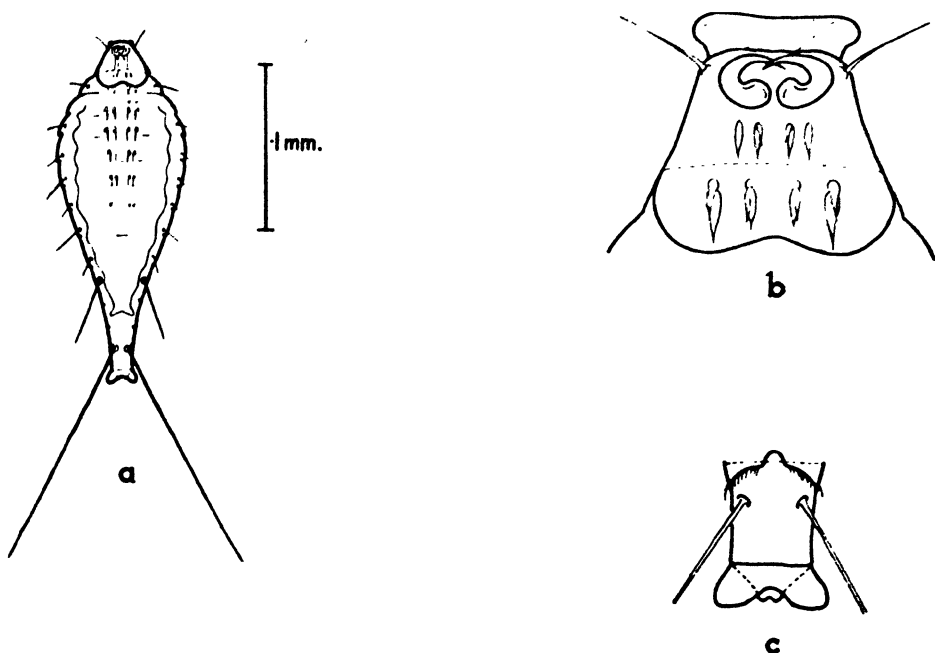


FIGURE 4. *Perilampus tristis* Mayr. (a) planidium, (b) anterior end, (c) posterior end (long setae not shown in full).

When unparasitised hosts are attacked by *Perilampus*, and no further parasitism occurs, the *Perilampid* larvae die; they only survive when further parasitism occurs, and are true hyperparasites, parasitising the primary parasites of *Cydia*. Superparasitism is common, as many as 8 panidia having been found in a single *Cydia* larva, although only 1 *Perilampus* emerges from the cocoon of the primary parasite.

The life history of *Perilampus* has been fully worked out by Smith (8), Bergold and Ripper (1), and is mentioned by Boyce (2). *Perilampus* eggs are laid on the apple foliage and fruit, and the highly mobile and sclerotised planidia, which were found to move by movements similar to those of a geometrid "looper" larva, enter the first stage codling moth larva as it wanders around before entering a fruit. Here the planidia remain without change until further parasitism occurs (the host larva may, of course, already contain an *Ascogaster* larva) and then, when the primary parasite larva begins to feed, with the consequent destruction of the host, the *Perilampid* planidium enters the parasite larva. When the latter is fully grown and has spun its cocoon, the planidium bores to the exterior and feeds ecto-parasitically on the parasite larva, pupates, and eventually emerges from the parasite cocoon. This species has also been seen to emerge from *Cryptus sexannulatus* cocoons. In this case the primary parasite is an ectoparasite, and the planidium must move from the paralysed

Cydia larva into the ecto-parasitic *Cryptus* larva and continue its development from this point (it has also been found in Canada to be parasitic on another ecto-parasite of *Cydia*—*Aenoplex carpocapsae* Cush.).

The hosts from which *Perilampus* emerged were:

Ascogaster quadridentatus Wesm.

Pristomerus vulnerator Panz.

Cryptus sexannulatus Grav.

(*Chrysopa* sp. . ? Secondary parasite).

Of 194 parasites emerging from a number of collections of larvae, 16 were *Perilampus*; hence 8 $\frac{1}{2}$ hyperparasitism occurred. The number of *Perilampus* emerging from *Ascogaster* cocoons was greater than that from *Pristomerus*, but this was only due to the relative abundance of these two parasites, since the *Perilampus* attack on the host is entirely independent of the other two species.

In the spring *Perilampus* was found to emerge some time after all the other parasites (see Figure 1), well at the end of the *Cydia* emergence period. As stated above, planidia were found in first stage *Cydia* larvae during dissections, and numerous specimens emerged from material collected while the *Cydia* larvae were still in the fruit. Emergence occurred:

July						August								
26	27	28	29	30	31	1	2	3	4	5	6	7	8	9
1	—	1	—	—	1	2	—	1	1	—	—	—	—	—
August														
10	11	12	13	14	15	16	17	18	19	20	21	22		
—	1	1	—	3	3	—	3	2	3	2	—	1		
23	24	25	26	27	28	29	30	31						
1	—	—	1	—	—	—	—	—						
September														
1	2	3	4	5	6	7-11								
1	—	1	—	1	—	1								

and there are thus at least two generations during the year. This species, by destroying a number of primary parasites, lessens the degree of biological control of *Cydia*, and this effect will be discussed later.

Dibrachys affinis Masi (*Chalcidae*, *Pteromalidae*)

A host list is given by Rosenberg (6) who reared this species from *Cydia* pupae. In the present work it was reared from the following two hosts:

Cydia pomonella L.

Pristomerus vulnerator Panz.

This species was not found as a secondary parasite in the field, but it was thought best to include it here since it did, in the laboratory, parasitise *Pristomerus* cocoons. It was reared from *Cydia* pupae found in "bands," and was not strictly from hibernating *Cydia* material, since only the pupal skin of the host remained, filled with full-grown larvae of the parasite. No diapause occurred, and cessation of development over winter was caused only by low temperature. In the "bands" hibernating adults were also found.

A number of experiments were conducted with this species, which are described below with similar experiments with *Dibrachys cavus* Wlk.

Dibrachys cavus Walk. (*Chalcidae*, *Pteromalidae*)

This common gregarious Chalcid has been recorded from a wide range of hosts. According to Rosenberg (6) "in the card index of the Farnham House Laboratory are records of its occurrence on: 11 species of Ichneumonidae, 16 species of Braconidae . . . , 2 species of Chalcididae, 3 species Tenthredinidae, 1 species of Lepidoptera . . . , 3 species of Coleoptera and 1 species of Neuroptera." He then mentions the fact that he bred it in the laboratory on pupae of *Cydia pomonella* L.

In the present work, both *Dibrachys cavus* and *D. affinis* Masi were reared, the latter only as an endoparasite of *Cydia* pupae, although in the laboratory it was bred ecto-parasitically on the larvae of *Pristomerus vulnerator*, Panz. The former Chalcid was an endoparasite of *Cydia* pupae, an ecto-parasite of full-grown *Cydia* larvae in their cocoons, and an ecto-parasite of larvae, prepupae, and pupae of the *Cydia* parasites—*Ascogaster quadridentatus* Wesm., *Pristomerus vulnerator* Panz., *Ephialtes caudatus* Ratz., *E. crassiseta* Thoms., *E. cydiae* Perk. and *Cryptus sexannulatus* Grav.

In the cases where *D. cavus* is a secondary parasite the eggs are laid on or near the Hymenopterous larva, prepupa or pupa within the cocoons (of the *Cydia* larva or parasite according to the stage attacked), and the young larvae feed gregariously through the skin of the host. However, when primarily parasitic on *Cydia*, *D. cavus* exhibits two forms of parasitism: (1) it is found as an ectoparasite of fully-grown larvae within their cocoons, the larvae being paralysed before oviposition; and (2) as an endoparasite of the pupae—(also noted by Boyce (2)). This peculiar behaviour was thought worthwhile investigating, and experiments were started in order to determine the host preferences of the ovipositing *Dibrachys* females, and also to ascertain whether there is anything of the nature of two biological races of the chalcid, one ecto- and the other endo-parasitic.

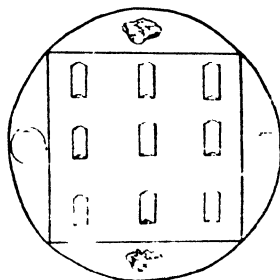


FIGURE 5. Petri dish with alternating *Cydia* and *Pristomerus* cocoons used in the host selection experiment with *Dibrachys*.

For host selection experiments different types of hosts were stuck with gum tragacanth alternately at regular intervals (as in Figure 5) on a piece of card, which was placed with *Dibrachys* adults in a petri dish and kept at 25° C., raisins and water being supplied for the adult parasites.

The hosts offered consisted of *Cydia* larvae and pupae, and cocoons of *Pristomerus vulnerator* containing larvae or pupae. All these were in the original *Cydia* cocoon, and this in turn was left in the small section of corrugated cardboard in which it had been spun.

Dishes were prepared with *Cydia* larvae alternating with pupae; others with *Cydia* larvae and *Pristomerus* cocoons. Four of each type were prepared, and into each were introduced 5 female and 5 male freshly emerged *Dibrachys cavus* adults, reared from ecto-parasites of *Cydia* larvae. The hosts attacked, and those from which progeny emerged were recorded. These experiments were then repeated but using adults bred endoparasitically from *Cydia* pupae; and finally again with *Dibrachys affinis* bred from *Cydia* pupae, and ecto-parasitically from *Pristomerus* larvae.

Unfortunately, all the detailed results of these and the following experiments are not available, since as stated above, they were lost during the French collapse of June, 1940. However, the final results were quite definite.

D. affinis attacked and parasitised *Cydia* pupae and *Pristomerus* cocoons even when the latter contained far advanced pupal stages. It never attacked *Cydia* larvae in their cocoons. On the other hand *D. cavus*, whether reared ecto- or endo-parasitically, attacked *Cydia* larvae and *Pristomerus* cocoons for preference, either being equally acceptable. If no other hosts were available the females parasitised *Cydia* pupae and the larvae developed endo-parasitically.

The above experiments indicate that *D. cavus* is not composed of two biological races—one with a preference for *Cydia* larvae as hosts, and the other for *Cydia* pupae. However, it was thought worth while investigating whether some preference for *Cydia* pupae might develop if *Dibrachys* were bred continuously on this host for a number of generations. A strain of *D. cavus* was bred on pupae for several generations and further host selection tests made. No such modification of host preference was recorded, and there was no influence exerted by the larval environment on the choice of host by the ovipositing female, which always showed a preference for *Cydia* larvae.

Thus the larvae of *D. cavus* and *D. affinis* can develop as endo-parasites, eggs being laid within the tissues of *Cydia* pupae, and also as ecto-parasites, the larvae feeding, in the case of *D. cavus*, externally on fully grown *Cydia* larvae, and larvae and pupae of several species of parasites; and in the case of *D. affinis* on various stages of *Pristomerus*. When *Pristomerus* cocoons were used as hosts, *Dibrachys* larvae were able to develop, not only on far advanced pupae, but also on the resting adults, when the soft abdominal tissues were consumed, the hard sclerotised parts remaining.

Imms (3) states "The factors that determine whether a species lives within or external to its host are evidently fundamental, since the endoparasitic mode of life involves a complete change in methods of respiration." The behaviour of *D. cavus* and *D. affinis* in this respect show that this statement is not always true, and the small size and apneustic condition of the young *Dibrachys* larvae permit of this internal feeding without any special respiratory adaptation. When larger, the endo-parasitic larvae within the host pupa have, no doubt, by the destruction of part of the host

tissues, formed air spaces sufficient for their respiratory requirements. There seems to be no other difference between the endo- and ecto-parasitic habit that would affect the physiology of the parasite larva, and it would be interesting to see if this facultative change of method of larvae feeding is of common occurrence.

Melittobia acasta Walk. (*Chalcidae*, *Eulophidae*)

The occurrence of this species from a *Cydia* pupa has already been recorded (Simmonds (7)). Four males and 7 females of *Melittobia* and 3 males and 13 females of *Dibrachys affinis* Masi emerged from a single *Cydia* pupa. It seems probable that the *Cydia* pupa was attacked first by the *Dibrachys*. Then, by the action of these endo-parasitic larvae in causing disruption of the host tissues and, consequently, air spaces, it was rendered suitable as a host for *Melittobia*, and was then attacked by this species.

ARTIFICIAL REARING OF PARASITES

It was thought possible that, once having obtained parasite eggs, it might be feasible to rear the larvae on artificial nutritive media. In eliminating the necessity for natural hosts, this would be of great use in large-scale breeding.

Owing to the difficulties presented by rearing endo-parasitic larvae thus, due to the respiratory requirements of the larvae, it was decided to experiment with ecto-parasites. A number of eggs were available from *Cydia* larvae superparasitised by *Ephialtes* sp., and *Cryptus*. Gelatine slopes were prepared (partly by Professor Urbain of Paris) of various compositions, and pieces of meat were also used. Parasite eggs placed on the media hatched normally, and the first stage larvae fed and grew. However, only in one case did moulting take place; the first stage larvae reached their normal maximum size and then died, as if some substance that promoted moulting was lacking from their diet. Dampened raw beef steak proved to be the most acceptable of the media tried, and it was on this that the one case of moulting occurred. It is hoped that further more extensive work on this problem will be done in the near future.

BIOLOGICAL CONTROL

In the South of France the percentage of parasitism of the various stages of *Cydia* was everywhere (except in the case of *Arrhinomyia tragica* Mg.) higher than those recorded by Rosenberg. A consideration of the percentages of the pest that are destroyed by parasite species shows that the total destruction they cause must be considerable. It is of interest to follow the codling moth through its annual cycle in the South of France, and try to estimate the effect of parasitism. It will be convenient to start with the eggs of the first summer generation which occur in the field after the middle of May. No egg parasites of the *Trichogramma* type were found, since work was commenced too late in 1939 and was stopped in 1940 before this could be adequately investigated. Sheets of waxed paper on which there were *Cydia* eggs were hung in apple trees in May, 1940, but no parasitism was observed. However, doubtless a certain amount of parasitism does occur.

Dissections of young larvae showed a total parasitism (excluding larvae parasitised by *Perilampus* alone) of 37.5%, 33.1% were parasitised by *Ascogaster*, 6.4% by *Pristomerus*, there being an overlap of these two species in 2% of the hosts, which had been attacked by both species. *Perilampus* attacked 3.7% of the total larvae, or 6.0% of the parasitised larvae.

Figures from the emergence records of this generation show 17.3% parasitism by *Ascogaster*, 4.1% by *Pristomerus*, 0.8% by *Trichomma* and 9.5% by *Perilampus*. *Trichomma* appears to be comparatively unimportant, and it is seen that *Perilampus* reduces considerably the number of emergents of *Ascogaster*. Since the material was removed from the field when the host larvae were young, it is possible that in the field the percentage parasitism by *Pristomerus* and *Trichomma* is greater than is indicated here.

Thus of these first generation larvae between 30% and 40% are parasitised before they spin their cocoons, chiefly by *Ascogaster*, the efficiency of which as a controlling agent, is considerably reduced by *Perilampus*.

Of these first generation larvae only about 50% emerge to give the second generation of *Cydia* in the summer, the other 50% remain as hibernating larvae within their cocoons until the following spring. Both hibernating cocoons and those which are to produce the second generation adults are subject to parasitism by *Ephialtes*, *Cryptus*, and *Dibrachys*, which further reduces the numbers of *Cydia* by about 10% of the now unparasitised larvae (or about 6% of the total larvae).

Thus, of the eggs laid by the spring emergents of *Cydia* about 50% go into hibernation (30 to 40% parasitised) until the following spring. The remaining 50% produce both parasites and hosts for a second generation, with a final result that under 20% of the original number of eggs laid produce adult *Cydia* in the summer generation; this does not, of course, take into consideration loss due to disease, predators, etc.

This second generation emerges in July and August, and there is a partial third generation in September, although the majority of the larvae from this second generation enter diapause and hibernate until the following spring. The eggs of this generation are again presumably parasitised by egg parasites; and figures from hibernating material show to what extent the larvae of this generation are parasitised. This shows that taking the collections as a whole 5.7% of the larvae were parasitised by ecto-parasites, and that of the remaining larvae about 32.7% were parasitised by endo-parasites (13.0% *Ascogaster*, 15.4% *Pristomerus*, 4.3% *Perilampus*). *Trichomma*, *Meteorus*, and *Arrhinomyia* only occurred in small numbers. Thus *Ascogaster* and *Pristomerus* are equally important as controlling agents, the efficiency of both being reduced by hyperparasitism by *Perilampus*.

Of the ecto-parasitism of 5.7%, 2.8% was by *Ephialtes*, 1.4% by *Cryptus*, 0.4% by *Dibrachys*, and 1.1% stung but not parasitised. From Table 3 it is seen that out of 47 cocoons of *Cryptus*, 27 *Cryptus* and 20 *Hemiteles* emerged, or that the numbers of *Cryptus* in the succeeding generation were reduced by 42.5% by the action of the secondary parasite.

As is seen from the emergence diagram (Figure 1) the ecto-parasites emerge in the spring some time before *Cydia*, and consequently further parasitism of hibernating material by the ecto-parasites occurs in the spring in addition to that recorded here—(and, incidentally, further secondary parasitism by *Hemiteles*).

To summarise; the first generation larvae in May are parasitised to the extent of 30% to 40%, together with 10% parasitism by ecto-parasites, and half of these go directly into diapause until the following spring, not emerging as moths in the 2nd generation. In the 2nd generation similar parasitism occurs, and in the spring hibernating host material is again attacked by ecto-parasites.

Thus it is seen that considerable parasitism occurs throughout the season. However, this parasitism was insufficient during the period of the investigation to prevent nearly all suitable fruit from being attacked.

The hyperparasite *Perilampus* and the secondary parasite *Hemiteles* are seen to cause considerable reduction in the numbers of emerging parasites, and it is possible that if not subjected to this restraint, the parasites might be able to exert greater control. *Perilampus tristis* Mayr. already occurs in Canada, as does *Ascogaster*, hence this part of the codling moth parasite complex is already established in that country.

It was thought that *Pristomerus*, *Ephialtes*, and *Cryptus* should be introduced, together, if possible, with *Trichomma*, *Arrhinomyia*, and *Meteorus*. *Dibrachys cavus* already occurs in Canada and *Dibrachys affinis* Masi is of doubtful value in view of its tendency to become a secondary parasite. In the case of *Cryptus* it was hoped that if it could be established in Canada without the check of *Hemiteles* it might become a successful agent in the control of the codling moth.

When the international situation became more difficult, a small shipment of *Cryptus sexannulatus* Grav. and *Ephialtes caudatus* Ratz. was made to Canada, and these species have been reared in the Dominion Parasite Laboratory, at Belleville, and liberations have been made in the Niagara peninsula in Ontario, although it is, as yet, too early to estimate their value as controlling agents.

SUMMARY

The species of parasites and predators attacking the various stages of the codling moth, *Cydia pomonella* L., in the South of France have been reared and their biology investigated.

Experiments were set up to determine whether fruit in any particular part of a tree was more liable to attack by *Cydia* than another, and whether at any part the degree of parasitism was higher. The influence of variety of fruit on parasitism and hibernation was also investigated.

The host preferences of one of the parasites, *Dibrachys cavus* Walk. were tested, in view of the peculiar behaviour of this species which can be either ecto- or endo-parasitic, according to its host.

The degree of biological control exerted is discussed, and recommendations made as to which species of parasites should be shipped to Canada to control the codling moth there.

ACKNOWLEDGMENTS

The investigations were conducted under the direction of Dr. W. R. Thompson, F.R.S. in charge of the Farnham House Laboratory of the Imperial Institute of Entomology, London; and acknowledgment is made for help and advice received from a number of French entomologists, in particular from Professor P. Regnier of Rouen, Dr. Vayssière of Paris, Professor Paillot of Lyons, and Dr. Poussard of Antibes. Thanks are also extended to Mr. F. Wilson of the Australian Department for Scientific and Industrial Research for accommodation in his laboratory at Le Lavandou.

The author is also indebted to Dr. Ch. Ferrière, Dr. J. F. Perkins, and Dr. F. van Emden for identification of material.

REFERENCES

1. BERGHOLD, G. and W. RIPPER. Zeit. für Parasitenkunde 9 Band, 3, Heft, p. 394. 1938.
2. BOYCE, H. Contrib. 2048, Div. of Ent. Sci. Serv., Dept. of Agric., Ottawa, Canada. 1940.
3. IMMS, A. D. Recent Advances of Entomology. 1937.
4. PERKINS, J. F. Bull. Ent. Res. 30 : 307-308. 1939.
5. PERKINS, J. F. Bull. Ent. Res. 33 : 171-174. 1942.
6. ROSENBERG, H. T. Bull. Ent. Res. 25 : 201-256. 1934.
7. SIMMONDS, F. J. Ent. Monthly Mag. 76, p. 137. 1940.
8. SMITH, H. S. U.S. Dept. Agric. Bur. Ent. Tech. Ser. No. 19. Pt. IV. 1912.

THE EFFECT OF HEAT, INSULATION AND ARTIFICIAL LIGHT ON EGG PRODUCTION AND FEED CONSUMPTION OF PULLETS¹

H. S. GUTTERIDGE², S. BIRD², H. I. MACGREGOR³ AND JEAN M. PRATT³

Central Experimental Farm, Ottawa

[Received for publication July 28, 1944]

Increasing the physical comfort of laying birds under both extremes of environmental temperature has very often been the subject of investigation. Protection against extreme cold has naturally been a problem of greater economic importance, however, and most controlled research has been in that direction. Artificial heat, insulation and the provision of adequate ventilation under varying conditions have been the principal subjects of experiment. The first large scale and most notable experiments on artificial heating and insulation were reported by Smith (7). His principal conclusions which bear on the work here reported were that insulation had a beneficial effect upon winter egg production; whereas the application of moderate heat was of doubtful value in this respect, and that humidity in the pen and winter egg production were not correlated. It is interesting also to note his finding that "closing a house up tightly all night during the winter period had no detrimental effect on winter egg production." Bruckner (2) reported heating to 50° F. to have a stabilizing effect upon winter egg production and to produce a non-significant but consistent small increase therein. A temperature of 60° F. affected health, body weight and egg size adversely and the use of temporary heat during cold spells did not increase winter egg production significantly. Of particular interest to the work to be reported was the statement that "laying hens in heated houses require less feed to produce a pound of eggs than those in unheated houses." No statement is made as to the amount of saving brought about. Lee (4, 5) after two years work states "the use of supplementary heat in an insulated laying house under the climatic conditions of Central New York State results in a lower annual egg production" While the great variability experienced between replicate pens indicates that the fact that heat actually reduced production may have been fortuitous, it is worthy of note that in spite of very low temperatures in the unheated pens the use of heat at least did not increase production.

Conditions of temperature during the winter months are very extreme in the area represented by this institution. Table 1 shown herewith, indicates the temperature at Ottawa to be much more rigorous than at Lincoln, Nebraska and Ithaca New York, referred to above. The last mentioned figures would also largely hold for the work done by Lee (*loc. cit.*) at Cayuga, New York. Not only is severe cold experienced but changes in temperature amounting to 40 to 50° F. sometimes occur within a period of 48 hours. Under these circumstances the benefits of artificial heat and insulation should be evident if such exist. From the winter of 1932-33 to that of 1942-43 a series of experiments was conducted dealing with the

¹ Contribution from the Division of Poultry Husbandry, Experimental Farm Service, Central Experimental Farm, Ottawa, Canada.

² Agricultural Scientists.

³ Agricultural Assistants.

TABLE 1.—A COMPARISON IN TEMPERATURE DURING WINTER 1933-34
AND OF LONG TIME AVERAGES

Month	Ottawa*			Cornell			Lincoln		
	Mean temp.	Normal mean	Lowest	Mean temp.	Normal mean	Lowest	Mean temp.	Normal mean	Lowest
	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.
December	5.1	17.3	-38	27.4	29.0	-13	32.8	27.6	-4
January	10.3	11.7	-34	27.6	24.3	-3	31.6	22.8	1
February	-2.7	12.7	-37	12.8	24.5	-24	30.2	26.1	-9
March	19.9	24.7	-12	32.2	31.8	5	38.0	37.5	8
Mean	8.2	16.6	-38	25.0	27.4	-24	33.2	28.5	-9

* Data by courtesy of the Division of Field Husbandry, Central Experimental Farm.

effects of heat and insulation. In 1939-40 artificial light was also used in a controlled way. The present paper places the results of these tests on record.

EXPERIMENTAL

With the exception of the experiment of 1942-43, which will be separately described, all tests were carried out in a 10-pen continuous laying house, each pen measuring 16 × 16 feet. Since it is important to establish the degree to which the birds were protected from the outside elements in the least protected pens (control pens) the following description is given and applies to all pens except for the modifications of greater insulation or artificial heat which will be noted.

Control pens (uninsulated): floor—concrete; ceiling—straw loft of 1" × 3" boards, 1" apart under joists with 12" of unpacked straw in loft above; roof—2" × 4" rafters, $\frac{3}{4}$ " sheathing, building paper and cedar shingles; rear wall—1" tongue and groove boarding with batons, building paper on 2" × 4" studs, with building paper and $\frac{7}{8}$ " shiplap, making a 4" dead air space; front wall— $\frac{1}{2}$ wood (single boarded) $\frac{1}{2}$ glass and $\frac{1}{2}$ cotton (screens), all three types of construction running the full length of the pen.

Semi-insulated pens: same construction as above except: ceiling— $\frac{1}{2}$ " insulation board under straw loft; rear wall— $\frac{3}{4}$ "-V joint over $\frac{1}{2}$ " insulation board built over shiplap of inner wall lining; front wall—1" boarding with batons, 2" × 4", sheathing and $\frac{3}{4}$ "-V joint over $\frac{1}{2}$ " insulation board on studding under windows; glass substitute (cel-o-glass) replaced cotton screens.

Insulated pens: same as semi-insulated pens except: front wall— $\frac{1}{2}$ glass and $\frac{2}{3}$ wood ($\frac{3}{4}$ "-V joint over $\frac{1}{2}$ " insulation board—no cotton or cel-o-glass screens).

Tightly boarded, insulated partitions separated uninsulated pens from semi-insulated and these in turn from insulated pens. Replicate pens within the above were separated by reasonably tight temporary partitions.

In terms of insulation as estimated from data published by Moore and Bell (6) and by Jones (3) the uninsulated pens had back and side walls of approximately 4.14 insulating value, whereas the semi-insulated and insulated pens had walls of 6.65 insulating value. The insulated pens, however, had the benefit of 6.65 insulating on the front wall over $\frac{2}{3}$ of the

front area, whereas the semi-insulated had such insulation over only $\frac{1}{3}$ of the front wall. The uninsulated pens had a $\frac{1}{3}$ front wall area of insulating value of 1.53, the remainder being glass and cotton of very low insulating value. Ceiling insulation was identical for the insulated and semi-insulated pens ($\frac{1}{2}$ " insulation board) but much lower for the uninsulated pens with straw loft. The hinged ventilating doors at each end of the house over the straw loft were kept closed throughout thus making a dead air-space of the loft.

The nature of the heat supply will be dealt with under separate headings. Temperatures were taken in the middle of the pen, 6" above the floor. Night temperatures were taken at mid-level of the birds above the roosts and in amongst them, by recording thermographs except for the 1932-33 and 1933-34 experiments when floor temperatures were used throughout. Humidity was taken by recording thermohygrographs or by sling psychrometer. All ventilation was by adjustment of windows or cotton screens hinged at the bottom with side baffles thus permitting entry of air only at the extreme top front of the house. Barred Plymouth Rock pullets balanced between pens according to date of hatch were used in all experiments.

The principal criteria used to determine the comparative merits of treatments were egg production, body weight and gain or loss in the latter. By the use of Bird and Sinclair's (1) partial regressions of these characters on total feed consumption the feed required for total maintenance was arrived at, and on the basis of requirements for resting metabolism by Diakow and basal metabolism by Brody as quoted by Bird (loc. cit) requirements for activity and work of digestion were allowed for, making feed requirement for basal metabolism, which is largely heat production, 60% of total maintenance. This figure was considered to be the closest estimate which could be made for feed required for heat loss from the body and is stated as feed for maintenance of body temperature.

RESULTS

The information gathered is shown for each year's experiments separately.

Experiment 1932-33

This test covered a period from November 18 to June 12. It comprised 3 pens heated with hot water pipes under dropping boards, 1 pen semi-insulated and 1 pen uninsulated. Since at that time it was thought that a smaller floor area per pullet would be required under heated conditions the 3 heated pens consisted of 75 birds each, the other 2 pens each containing 50 birds. Lowest temperatures experienced inside the pens for the different treatments were: heated 38° F., semi-insulated 27° F. and uninsulated 10° F. Lowest outside temperature was 25° F. below zero.

Table 2 shows the essential data obtained. It is immediately evident that neither heat nor insulation had any effect upon egg production, the differences being small and within the range of error of the test. It must be assumed therefore that equal opportunity for egg production exists at mean temperatures of 38.° F. or 51.2° F. Body weight gains also did not differ significantly. Feed required for maintenance of body heat did

TABLE 2.—THE EFFECT OF HEAT AND INSULATION ON EGG PRODUCTION AND FEED CONSUMPTION

1932-33	No. of birds	Mean temp.	Body wt. gain	Feed consumption	Feed for maintenance of body temp.	Egg production
		° F.	gm./bird	gm./bird/day	gm./bird/day	gm./bird/day
Heated (3 pens)	225	51.2	78.4	106.5	49.8	29.3
Semi-insulated	50	42.6	86.5	117.3	54.6	32.8
Uninsulated	50	38.0	90.6	114.9	53.8	31.3

not parallel pen temperature which is not surprising in view of the measure of error which is inherent in all estimates of this kind. However, the maximum increased requirement for maintenance of body heat in the coldest pen was 4.8 gm. per bird per day. Since it is the case that this saving could be made only for the winter months, or roughly 150 days, then the annual saving per bird per year would be approximately 1.6 lb. per bird. It will at once be appreciated that such a small saving would hardly justify installation of heating plant, fuel and labour costs in heating such a poultry house. Further the cost of the additional insulation of the semi-insulated pen was not justified by these data. In considering the above data it must be realized that the heavier population of the heated pens may have had an undeterminable effect upon the performance of these pens. It probably might be expected, however, to affect such factors as livability or cannibalism rather than egg production.

Experiment 1933-34

This experiment covered the period from November 15, 1933 to April 14, 1934, a period of 140 days. The experiment of the previous year was repeated but since temperature of the heated pens had fluctuated to a greater extent than was desirable, adjustments were made to the heating and ventilating equipment which resulted in a somewhat smaller range of temperature. It was found to be impossible, however, to keep it from slightly exceeding 60° F. when very sudden upward changes of outside temperature occurred. Lowest temperatures experienced inside the pens for the different treatments were: heated 40° F., semi-insulated 19° F., uninsulated 16° F. Lowest outside temperature was 38° F. below zero.

TABLE 3.—THE EFFECT OF HEAT AND INSULATION ON EGG PRODUCTION AND FEED CONSUMPTION

1933-34	No. of birds	Mean temp.	Relative humidity	Body wt. gain	Feed consumption	Feed for maintenance of body temp.	Egg production
		° F.	%	gm./bird	gm./bird/day	gm./bird/day	gm./bird/day
Heated	55	50.6	61	245	95.3	44.1	22.8
Heated	55	49.9	63	248	100.7	46.7	24.0
Semi-insulated*	55	45.6	86	245	103.4	49.2	22.6
Semi-insulated	55	43.8	85	338	106.3	50.3	23.1
Uninsulated	55	42.1	86	283	104.2	50.3	20.5
Uninsulated	55	39.1	87	500	113.5	53.8	24.2

* No ventilation.

Table 3 shows the results obtained. Approximately the same mean temperatures were experienced in the pens under the different treatments as was the case in the previous year's test. Relative humidity was recorded in this instance and showed the air to be relatively drier in the heated pens. Again no significant differences occurred in egg production. The feed required for maintenance of body temperature followed the change in temperature in the different pens to a gratifying degree, indicating a reasonably accurate estimate of feed required for this purpose to have been obtained. The temperature in the warmest of the heated pens was 10.5° F. higher than that of the coldest uninsulated pen, for a maximum saving in feed for maintenance of body temperature of 9.7 gm. or 3.2 lb. of feed per bird annually. No significant difference occurred between feed required for maintenance in the semi-insulated and uninsulated pens, and the greatest difference represents a saving of 1.5 pounds of feed per bird per year. Relative humidity obviously had no effect on any of the criteria considered.

The pen shown in Table 3 as semi-insulated with no ventilation is of particular interest. In this pen the cotton screens, which when closed are the only source of change of air, were kept closed continuously throughout the test and were covered over with insulation board so that the only ventilation which the birds received was any change of air which took place through cracks around windows and partitions between pens which undoubtedly was very small. The result as shown by the table was a warmer pen than its duplicate by 1.8° F. with a higher relative humidity by 1%. The condition of absolute humidity was much greater than is indicated by Table 3, however, since the walls and litter were continuously wet from condensed moisture and there was a heavy concentration of ammonia in the air. Carbon dioxide, determined from samples taken with mine flasks under the roosts at night was 0.73% in this pen as compared to 0.28% in one of the heated pens. Under these conditions the performance of the birds was the equal of that of any other treatment and it would appear that birds can stand low temperatures with high humidity and relatively heavy concentration of ammonia and carbon dioxide over an extended period very well indeed.

Experiment 1939-40

This experiment covered the period November 22 to April 10 or 154 days. In this instance fully insulated pens without heat were used for the first time. Also since no benefit had accrued when heat at 50° F. had been used it was lowered to 45° F. during the whole of this test. In addition, since the hot water system still permitted a fairly large range in temperature in the pens thus treated, thermostatically controlled electric heating equipment was installed and this reduced the variability to $\pm 4^{\circ}$ F. on the average.

Lowest temperatures experienced inside the pens for the different treatments were: heated 40° F., insulated 28° F., semi-insulated 26° F., uninsulated 26° F. Lowest outside temperature was 19° F. below zero.

Table 4 shows the data obtained. An outstanding feature of these data is the higher mean temperature in the semi-insulated and uninsulated pen than was the case in the completely insulated pen. An examination

TABLE 4.—THE EFFECT OF HEAT AND INSULATION ON EGG PRODUCTION.

1939-40	No. of birds	Mean temp.	Relative humidity	Feed consumption	Egg production to March 20	Egg production to Sept. 4
		° F.	%	gm./bird/day	no.	no.
Heated	55	45.3	81	129.7	87.7	195.7
Insulated	55	37.1	91	132.8	86.2	193.3
Semi-insulated	55	39.2	88	133.5	93.4	192.5
Uninsulated	55	37.8	88	136.0	89.0	194.4

of the charts from the thermographs showed the reason for this condition to be the consistently higher mid-day and afternoon temperatures in the semi-insulated and uninsulated pens on sunny days. Since the winter climate in this area is characterized by cold days with brilliant sunlight the cumulative effect of this sunlight shining through glass and glass substitute was to raise the mean temperature of these 2 pens to an appreciable degree. Since the insulated pen had been more completely insulated by substituting insulated wall for one-half the window area, the effect of the sun was not nearly so pronounced in this pen. It is significant to note that in this instance the effect of additional glass area was sufficient to nullify the effects of thorough insulation. Had the cotton screens of the uninsulated pens been replaced by glass these pens would probably have been almost as warm as the semi-insulated pens.

The egg production to March 20 or during the cold period of the year did not differ significantly for any group. At September 4, close to the end of the laying year, production was still almost identical for all groups. Sufficient data were not available to estimate feed required for maintenance in this case, but production being almost identical it may be assumed from the figures for total feed consumption that the amount used in offsetting the greatest difference in temperature of 8.2° F. was negligible.

Experiment 1941-42

This test covered a period from November 17, 1941 to March 22, 1942. All heating was again electrical and thermostatically controlled. Besides heating 2 groups to 54° F. and 59.9° F., respectively, 1 fully insulated group was heated at night only, by running resistance wire the full length of the under side of the roosts. It was reasoned that the warmth of sunlight and activity might bring about satisfactory conditions of temperature during the day and the relative inactivity of roosting might result in the need for some supplementary heat during the night. One other change in treatment was made, namely, that the ventilation of the semi-insulated pen was restricted in contrast to the situation in all other experiments in which (with one exception previously noted—1933-34) an attempt was made to have the same amount of ventilation in all groups. In this pen the sliding ventilators in the glass substitute screens were kept with a minimum of opening during morning and late afternoon and opened relatively wide during the warmest hours of mid-day when the sun was shining thus permitting the escape of moist air and maintaining a litter condition similar to that of comparable pens. At night the slides were closed entirely.

Lowest temperatures experienced inside the pens for the different treatments were: heated 56° F., heated 51° F., heated (night) 42° F., insulated 32° F., semi-insulated 35° F., uninsulated 22° F., uninsulated 20° F. Lowest outside temperature was 21° F. below zero.

TABLE 5.—THE EFFECT OF HEAT AND INSULATION ON EGG PRODUCTION AND FEED INTAKE

1941-42	No. of birds	Temperature			body wt. gain gm./bird	Feed consumption gm./bird/day	Feed for maintenance of body temp. gm./bird/day	Egg production gm. bird/day
		Day	Night	Mean				
		° F.	° F.	° F.				
Heated	30	57.6	61.1	59.9	298.9	125.1	55.4	37.9
Heated (night only)	30	52.3	59.9	57.4	255.4	132.2	59.3	39.2
Heated	30	51.0	55.5	55.0	243.6	129.6	56.9	41.2
Insulated	55	42.9	44.3	43.8	183.2	142.1	66.4	37.3
Semi-insulated*	55	49.9	50.4	50.2	254.0	126.8	58.0	35.9
Uninsulated	55	42.6	45.2	44.3	201.2	149.8	69.6	39.8
Uninsulated	55	42.0	43.4	42.9	230.9	147.3	67.8	39.7

* Restricted ventilation.

Table 5 shows the results obtained. The pen heated at night only was 5.3° F. colder during the day than the warmest of the heated pens. Also, by restriction and control of ventilation the semi-insulated pen had a uniform day and night temperature approximately 7° F. higher than the insulated pen. This was accomplished without the excessive dampness characteristic of non-ventilated pens by judicious adjustment of ventilation during the warmest portion of the day. The greater window space of this pen again contributed to the higher temperature achieved and nullified the effect of complete insulation. Differences in egg production are not significant and production was quite good for the completely uninsulated pens. The greatest difference in feed required for maintenance was 14.2 grams per bird per day for a temperature difference of 15.6° F. On this basis the application of heat saved 4.7 lb. of feed per bird annually.

Experiment 1942-43

Since by far the most difficult matter to determine experimentally is the saving in feed accomplished through the application of heat to the pens, an experiment was planned for the sole purpose of measuring this factor. Since it was desirable to have as wide a range in temperature as possible, small, poorly insulated pens were used so that a very low temperature would be the result in the unheated pen. Electric heat was impossible under these conditions and a brooder stove was used in the heated pens. Colony houses 10' X 12' were used which had double boarded walls with building paper on studding forming a 4"-dead air space for back and side walls. The fronts were $\frac{1}{3}$ wood, $\frac{1}{3}$ glass and $\frac{1}{3}$ cotton and the ceiling was 4-inch thick straw loft between the 2" X 4" rafters of a shed roof. A small number of very late hatched birds was used so that the egg production was not of use as a direct measure of comparison. The feed required for this purpose could of course be estimated satisfactorily. The test covered a period from December 11, 1942 to March 29, 1943, a period of 109 days.

Lowest temperatures experienced inside the pens for the different treatments were: heated 28° F., heated 20° F., unheated 4° F. below zero. Lowest outside temperature was 36° F. below zero.

TABLE 6.—EFFECT OF HEAT ON REQUIREMENT OF FEED FOR MAINTENANCE OF BODY TEMPERATURE.

1942-43	No. of birds	Mean temperature	Feed consumption	Feed for maintenance of body temperature
		° F.	gm./bird/day	gm./bird/day
Heated	27	52.3	89.69	45.6
Heated	48	47.8	96.00	48.2
Unheated	28	32.0	97.12	51.5

Table 6 shows the information obtained. It was found to be difficult to maintain the range of temperature which was intended between heated houses hence the results of 2 houses which had the same mean temperature were combined. Under unusually cold winter conditions, a temperature range of 20.3° F. was experienced with the mean temperature for the whole period being as low as 32° F. in the unheated pen. Great care was taken to have accurate figures on production, body weight and feed consumption. It was found that a saving of 5.9 gm. of feed per bird per day or 1.9 lb. of feed per bird per year was made. It was noted that the birds of the cold pen quite obviously attempted to adjust themselves to their environment. This consisted in a lowering of activity through standing in groups with the feathers ruffled, thus decreasing feed requirement to support activity, conserving heat by crowding together and increasing the insulating value of the feathers against heat loss from the body by entrapping more air amongst the feathers. It is suggested that these two factors begin to operate when temperatures go below a certain undetermined minimum thus making the environment more suitable to the bird. This factor makes the data for feed requirement for maintenance from this test not strictly comparable with that of those previously reported since these reactions were rarely noticed in previous experiments. The cost of fuel to bring about a temperature of 52.3° F. under these severe conditions was out of all proportion to practicability.

Artificial Illumination 1939-40⁴

A test involving a very large number of birds with 4 replications for each treatment was carried out to determine the effect of artificial light upon egg production. The lighted period was from October 5, 1939 to April 2, 1940, or 180 days. Morning lights were used and were turned on and off automatically to give sufficient artificial light to counteract the increasing and then decreasing hours of darkness before and after December 21, respectively, giving a reasonably constant light day of approximately 13 hours.

Table 7 shows the pertinent data, indicating a consistent effect of lights both in the case of replicate groups and the overall mean values.

⁴ Project planned and carried out by Dr. S. S. Munro of this Division.

TABLE 7.—EFFECT OF LIGHT ON EGG PRODUCTION

1939-40	No. of birds	Feed consumption	Egg production to Mar. 20	Egg production to May 6	Egg production to Aug. 7	Egg production to Sept. 4
		gm./bird/day	No.	No.	No.	No.
Lighted						
Pen 1	55	132.7	78.0	110.7	179.8	190.5
3	55	137.5	86.1	124.1	177.3	197.2
5	55	140.6	78.6	124.3	169.0	192.5
7	55	151.6	81.9	116.8	172.2	194.5
Unlighted						
Pen 2	55	126.7	74.4	118.2	171.0	195.7
4	55	128.1	63.3	110.2	167.8	193.3
6	55	126.4	57.8	99.0	160.8	178.0
8	55	120.2	57.2	103.0	163.3	181.8
Lighted	220	140.6	81.1	119.0	174.6	193.6
Unlighted	220	125.4	63.2	107.6	165.7	187.2
Unlighted less than lighted %			22.1	9.6	5.1	3.3

At March 20 which is the end of the calendar period most closely approximating the date of discontinuance of illumination, a significant difference in egg production had been brought about through the use of lights representing 17.9 eggs per bird or 22.1%. Between this point and May 6 a sharp decrease in rate of production for the lighted group reduced the difference to 11.4 eggs per bird and to August 7 and September 4 to 8.9 and 6.4 eggs per bird, respectively. This is in line with the findings of many other investigators.

DISCUSSION

Most of the evidence presented in this paper relates to the application of artificial heat and the provision of insulation for the purpose of improving the physical comfort of laying birds. To be valid, an estimate of the effect of these factors should be made under conditions of severe cold which is provided in this instance by the climatic environment of the area in which this institution is situated (see Table 1). This, as may be judged by the meteorological data, is more severe than that of most areas in which poultry are kept on a commercial scale on this continent. Improving the physical comfort of the bird above a reasonable minimum is of little import unless the economy of its output is raised thereby. In this instance the installation of heating equipment, the fuel required for its operation as well as the cost of providing sufficient insulation to the building to make the operation of a heating unit reasonably economical or the raising of the temperature of the laying pen by insulation alone, must be considered. The saving of feed and litter are also matters for consideration.

The data presented herein show quite conclusively that the output of the bird is not improved by the application of heat or the provision of additional insulation. Experiments covering four years have consistently shown as high egg production in uninsulated, unheated pens as under conditions of heat or insulation. Mean temperatures in the pen during the winter months of 37.8° F., 39.1° F. and 42° F. gave as high egg production

as did those of 45.3° F., 50.6° F. or 59.9° F. Body weight gain also was not affected by temperatures within this range, variations which did occur being obviously unrelated to environmental temperature and caused by other factors.

Increase in environmental temperature must however, be reflected in a lowered heat loss from the body which means either a saving in actual feed consumption or the sparing of body supplies of fat which otherwise might be burned up in the process of maintaining body heat. An estimate of feed required to maintain body temperature was therefore made to determine the approximate saving in feed induced by higher environmental temperatures when production of eggs and gain in body weight were held constant. In 4 separate experiments in different years a saving of feed was accomplished during the winter months of 1.6 lb., 1.9 lb., 3.2 lb., and 4.7 lb. per bird under varying degrees of temperature difference. There is no substantial lack of agreement between these figures in so far as feed requirement and temperature range is concerned excepting in the case of the 1941-42 data where the requirement of feed for maintenance of body heat is very large in relation to the severity of the lowering of temperature. Since allotment of the feed consumed to that required for weight gain and egg production and its deduction from the total feed was carried out in an identical way to that of the other experiments, the total feed consumption, if anything, is at fault. Very careful checking indicates these figures to have been correct and it is difficult therefore to explain the larger feed requirement per degree of temperature decrease in this instance. Greater reliance can be placed, however, upon the 1942-43 figures, hence it is assumed that the figure for that year is probably a better estimate of the true situation. To be conservative the mean value for the four years of 2.85 lb. per bird for maintenance of body temperature is considered to be the best estimate of the saving possible under the temperature ranges quoted above, and a very small saving indeed was involved in the application of heat or insulation. Admittedly, a considerable saving in litter and labour of changing litter in the heated pens is involved. This saving is at least counteracted by the costs of installation of heating equipment and fuel consumed. Application of the results of these findings must be conditioned by the important fact that a temperature range at the level of the birds of from 37.8° F. to 59.9° F. was the case in these tests. Much lower temperatures might have a different effect but the observation that no greater saving of feed was accomplished at a mean temperature of 32° F. and of the behaviour of the birds in adapting themselves to this temperature by ruffling of the feathers to increase their insulating power and in other ways would suggest that the above findings would hold for a much lower temperature range. In further support of this contention, at the Experimental Station, Kapuskasing, Ontario, under very severe weather conditions in a preliminary test using 2 pens of 50 birds, heated and 2 pens unheated, egg production was 72.3 eggs per bird for the heated groups and 69.8 eggs for the unheated from November 1 to April 1, a negligible difference. The mean outside temperatures for each of the 6 months were 22.2° F., 7.2° F., -1.5° F., 2.5° F., 13.6° F. and 31.1° F. Our records show a series of 30 consecutive days at Kapuskasing only 2 of which were above zero and going as low as 43° F. below zero. Inside pen tempera-

tures in the test under consideration averaged 14° F. lower than was usually the case in Ottawa experiments. On September 4 the production of these groups was 185.2 and 190.6 eggs per bird respectively. Under the meteorological conditions in the Ottawa area a house constructed similarly to the uninsulated pens of these tests may be expected to give as high egg production as heated or well insulated pens at only a very slightly greater increase in feed consumption. This construction is as follows: boarding of rear and side walls inside and outside of the studs with paper between boards and the studding making a 4-inch air space, with $\frac{1}{3}$ wood, $\frac{1}{3}$ cotton and $\frac{1}{3}$ glass front construction, and straw loft ceiling.

Attention is drawn to the fact that by judicious adjustment of the ventilation, that is, no ventilation at night and increased ventilation during the warmest part of the day to change air and remove moisture, an increase in mean temperature of 7° F. was accomplished which gave the pen thus treated the equivalent of heat at 50° F.

The effect of artificial illumination is also briefly recorded showing a definitely increased egg production for the lighted pens during the winter months but an almost identical production at the end of the laying year.

SUMMARY

Four separate experiments carried out in different years between 1932-33 and 1941-42 contrasting artificial heat, two different degrees of insulation, and uninsulated pens are reported as well as a test to determine the saving of feed accomplished by artificial heat under an extreme range of temperature conditions. A 1-year test of the effect of artificial illumination is also recorded.

From the consideration of the data obtained the following conclusions seem justified:—

1. Increasing the environmental temperature of laying pullets by the use of artificial heat and insulation over a range of 37.8° F. to 59.9° F. had no effect upon egg production. Even when temperature was thermostatically controlled to a range of $\pm 4^\circ$ F. in the heated pen no improvement in production was obtained.

2. The maximum saving in feed accomplished through the decreased requirement of feed for the maintenance of body temperature under heated conditions was 4.7 lb. per bird annually with a mean saving of 2.85 lb. The mean inside pen temperature range in these tests was from 32° F. to 59.9° F.

3. Restriction of ventilation to a minimum, all ventilators being completely closed with a resulting temperature of 45.6° F. and very high humidity and carbon dioxide content of the air had no detrimental effect upon egg production.

4. The reduction of window area in an attempt to supply more insulation is not justified under conditions similar to those in this test since the effect of reducing window space by one-half, because of exclusion of sunshine, nullified the effect of complete insulation and gave equal or higher mean temperatures in the uninsulated pens.

5. The use of artificial illumination significantly increased egg production during the winter months but resulted in approximately the same annual production.

It is concluded that laying pullets will produce well under a very wide range of temperatures and conditions of humidity, and that neither artificial heat nor insulation, as herein defined, would be justified under temperature conditions similar to or less severe than those experienced in this area. These conclusions have been arrived at under conditions of severe cold and therefore constitute a severe test of the housing conditions investigated.

REFERENCES

1. BIRD, S. and J. W. SINCLAIR. A study of the energy required for maintenance, egg production and changes in body weight in the domestic hen. *Sci. Agr.* 19 : 8; 542-50. 1939.
2. BRUCKNER, J. H. The effect of environmental conditions on winter egg production. *Poul. Sci.* 15 : 5; 417. 1936.
3. JONES, R. E. The Connecticut 24' \times 24' poultry house. *Bull.* 347. Univ. Conn. Ext. Service. 1944.
4. LEE, C. E., S. W. HAMILTON, C. L. HENRY and M. E. CALLANAN. The effect of supplementary heat on egg production, feed consumption, amount of litter required, and net flock income. *Poul. Sci.* 16 : 4; 267-73. 1937.
5. LEE, C. E., S. W. HAMILTON, C. L. HENRY and M. E. CALLANAN. The effect of supplementary heat on egg production, feed consumption, amount of litter required and net flock income. Part 2, *Poul. Sci.* 18 : 5; 359-68. 1939.
6. MOORE, J. M. and A. J. BELL. Laying houses. *Bull.* 233, Mich. State Ext. Service. 1943.
7. SMITH, CHAUNCEY W. The relation of environmental conditions in poultry houses to winter egg production. *Bull.* 247, Neb. Exp. Sta. 1930.

THE DIGESTIBILITY OF TYPICAL EASTERN CANADIAN FEEDS BY MARKET BACON HOGS, III.¹

E. W. CRAMPTON² AND J. M. BELL³
Macdonald College (McGill University), Quebec

[Received for publication August 7, 1944]

As a sequel to reports on previous study in this laboratory on the digestibility of feeds by swine this paper presents further work on the investigation started in 1941⁴.

Concurrently with the determination of digestibility coefficients of the proximate principles of the standard feeding stuffs analysis, studies were continued on the proposed system of feeding stuffs analysis as reported by Crampton and Whiting (1).

EXPERIMENTAL

The animals chosen for the test were 4 closely related Yorkshire barrows. They commenced trial periods at weights of 50, 100, 150, and 200 pounds.

Table 1 shows the allotment of the pigs by weights, feeds, and trial periods. The digestion crates have been described previously (2).

TABLE 1.—PLAN OF DIGESTION TRIALS, SHOWING NUMBERS AND ALLOTMENT OF ANIMALS TO FEEDS IN EACH PERIOD

Rations	Period 1 50 lb. pig	Period 2 100 lb. pig	Period 3 150 lb. pig	Period 4 200 lb. pig
No. 2 Yellow Corn	78	79	47	61
No. 2 N. Wheat	79	47	61	78
Degermed Shorts	47	61	78	79
Standard Shorts	61	78	79	47

The swine feeds tested during 1943 were yellow corn, wheat, and two kinds of wheat shorts; one sample containing the germ while the other had had most of the germ removed in the process of preparation of "Canada Approved" flour. Though not now differentiated from standard shorts it seemed probable that degerming might sufficiently alter the feeding value of the latter product that some distinction would be necessary between the two types of shorts as livestock feeds.

In addition to the digestion period schedule, as planned, an extra test was introduced between periods 2 and 3 in which all animals were fed degermed shorts.

¹ Contribution from the Faculty of Agriculture, McGill University, Macdonald College, Que., Canada. Journal Series No. 191.

² Professor of Animal Nutrition.

³ Graduate Assistant, Department of Nutrition.

⁴ These studies were made possible through the financial assistance of the Quebec Department of Agriculture.

It was necessary to obtain a new sample of corn for periods 3 and 4 because of a rancid condition that developed in the original mixed ration.

A protein-mineral supplement consisting of 25 parts meat meal, 40 parts linseed oil meal, 15 parts fish meal, 10 parts bone char, 5 parts ground limestone and 5 parts salt was fed with all the basal feeds in all tests at the rate of 15% of the total ration (see Table 2 for analysis). In addition, cod liver oil was fed daily during the first two periods.

Feeding was done three times daily to pigs under 150 lbs., i.e., during periods 1 and 2, and twice daily to heavier pigs. Between trials the animals were removed to the farm piggery where they were maintained on a ration of equal parts of wheat and barley, supplemented as in the experimental diets.

A preliminary period of 5 days preceded each 10-day collection period in order to clear the digestive tract of previous dietary residues and adjust the feed consumption of the animals to full and constant feed intakes before the excreta collections commenced.

Faeces collections were made once daily at approximately 9.00 o'clock in the morning. Representative aliquots were taken for chemical analysis.

Urine was collected twice daily at 9.00 a.m. and 5.00 p.m. One one-hundredth (1/100) aliquots were preserved under toluene in H₂SO₄ and acetic acid during each trial. Nitrogen determinations were made by the Kjeldahl method.

The percentage composition of the basal feeds and supplement are presented in Table 2.

TABLE 2.—CHEMICAL COMPOSITION OF BASAL FEEDS AND SUPPLEMENT

Feed fraction	No. 2 Yellow corn		No. 2 Canadian northern wheat	Degermed shorts		Standard shorts	Supple- mixture
	Sample 1	Sample 2		Sample 1	Sample 2		
Water	9.0	9.0	11.0	10.0	9.0	10.0	8.5
Protein (N × 6.25)	8.9	9.0	16.4	20.0	19.2	17.8	34.8
Soluble protein*	6.2	7.0	14.6	16.7	17.7	15.3	30.3
Insoluble protein*	2.7	2.0	1.8	3.3	1.5	2.5	4.5
Ether extract	1.9	2.8	1.5	4.4	4.2	3.9	5.0
Total ash	1.6	1.4	1.4	4.3	5.2	4.1	25.5
Carbohydrates							
Crude fibre	2.7	2.1	2.4	8.6	9.8	10.4	6.6
Nitrogen-free extract	75.9	75.7	67.3	52.7	52.6	53.8	19.6
Carbohydrates*	2.1	1.9	2.0	6.9	8.2	7.0	4.6
Soluble carbohydrates	75.8	75.0	66.2	50.3	47.2	50.9	17.8
Lignin (by difference)	0.7	0.9	1.5	4.1	7.0	6.3	3.8
Lignin** + Insol. protein	3.9	3.3	3.9	8.4	9.6	9.9	9.3

* From scheme of feeding stuffs analysis by Crampton and Whiting. (See Appendix).

** Lignin determined directly and added to Insoluble Protein.

DIGESTIBILITY OF FEED CONSTITUENTS

The "by-difference" method of calculating the digestibility coefficients was employed for the basal feeds studied, using the formula:

$$Cx = \frac{mR - [F - R(n)(1.00 - Cy)] \times 100}{mR}$$

where m = percentage of nutrient contributed by basal diet.
 n = percentage of nutrient contributed by supplement mixture.
 R = weight of total ration or ration constituent consumed.
 F = weight of total faeces or faeces constituent produced.
 Cy = the digestibility coefficient of the constituent in the supplement mixture.

Digestibility coefficients obtained on the four basal feeds are presented in Table 3 along with some comparable coefficients obtained with ruminants by other investigators. No significant differences were noted between the two corn samples so the average coefficients are reported in the table. All calculations were made on the regular 10-day time collections.

TABLE 3.—COEFFICIENTS OF DIGESTIBILITY, TOTAL DIGESTIBLE NUTRIENTS AND DIGESTIBLE CRUDE PROTEIN OF FEEDS LISTED

	No. 2 Yellow corn	No. 2 Canadian northern wheat	Degermed shorts	Standard shorts	Supplement mixture	Degermed shorts (Sample 2)*
Dry Matter	90	88	67	68	43	63
Organic Matter	88	85	65	67	50	63
Protein (N × 6.25)	88 (76)	89 (86)	79	81 (85)	71	81
Soluble Protein	89	92	86	88	82	87
Insoluble Protein	87	66	46	38	0	74
Ether Extract	38 (91)	32 (83)	50	47 (85)	100	41
Carbohydrates†						
Crude Fibre	37 (57)	—1 (90)	17	26 (60)	37	19
Nitrogen-Free-Extract	94 (94)	94 (95)	76	77 (85)	0	73
Carbohydrates‡						
Cellulose	24	—6	15	15	32	19
Soluble Carbohydrates	97	95	78	79	8	75
Lignin (by difference)	—94	7	19	47	15	44
Lignin + Insol. Protein	42	37	31	46		35
Digestible Crude Protein	8 (7)	15 (11)	16	15 (15)	25	16
Total Digestible Nutrients†	83 (81)	79 (84)	62	63 (76)	32	59
Total Digestible Nutrients‡	83	78	62	60	33	56

* Shorts fed during separate trial between Periods 2 and 3.

† By Proximate principles scheme of feedstuffs analysis.

‡ Method proposed by Crampton and Whiting. (See Appendix.)

Figures in parentheses are digestion coefficients obtained from tests with ruminants on similar feeds.

In Table 3 are included determinations by the Crampton and Whiting procedure for feeding stuffs analysis. Carbohydrates were divided into cellulose, soluble carbohydrates and a lignin-by-difference fraction for comparison with the crude fibre and nitrogen-free-extract division. Coefficients are also presented for a fraction representing the lignin (direct) plus the "insoluble protein" (i.e. insoluble after refluxing for 3 hours in 1% HCl. See appendix.)

DISCUSSION

The digestibility of dry matter was significantly higher in the case of wheat and corn than in shorts. It is probable that the laxative properties of the shorts were an influential factor in depressing the apparent digestibility of their dry matter.

The ether extract, a fraction which showed rather variable results, was slightly better digested in shorts than in corn or wheat.

Crude fibre digestibility coefficients in all cases were very low. The coefficients were higher in standard than degermed shorts. There is no theoretical reason for this, which leads to the conclusion that crude fibre isolated in the one case differs from that obtained in the other as later mentioned. In contradistinction to this is the case of cellulose where the digestibility of this fraction is the same for each type of shorts. The erratic values of whole wheat are explainable on the basis of low crude fibre in the basal feed itself and the errors inherent in the "difference" method of calculation. The crude fibre of corn was better digested than that of wheat as shown by both wheat and shorts.

The digestibility of nitrogen-free-extract in corn and wheat was about equal, both the coefficients in the entire grains being considerably higher than in the shorts samples.

Coefficients for soluble carbohydrates parallel those obtained for nitrogen-free-extract as could be expected because of the similarity between these fractions in concentrate feeds. Soluble carbohydrates probably tend to be better digested because the proposed scheme of analysis relegates some of the formerly indigestible nitrogen-free-extract fraction to the less digestible fraction called lignin-by-difference. Consequently the remaining nutrients of the nitrogen-free-extract, the soluble carbohydrates, constitute the more highly digestible and probably more useful fraction.

"Lignin" gave very low and irregular results with corn and wheat where the percentage lignin in the basal feeds was small and hence subject to greater error in determination. The coefficients for shorts were however consistently higher than in the case of the whole grains.

Another fraction, lignin plus "insoluble protein", (see appendix) which was not included in either of the schemes of feeding stuffs analysis, showed digestibility coefficients of a more consistent nature than the lignin-by-difference fraction. No negative values for this fraction were obtained for any of the feeds studied.

The crude protein in corn and wheat appears to be better digested by swine than the protein in shorts. This is most likely due to the effects of the lower fibre content of the grains.

Data relative to the usefulness of protein in these feeds are presented in Table 4.

TABLE 4.—NITROGEN DIGESTED, RETAINED AND EXCRETED BY PIGS

Ration	Percentage of total nitrogen digested	Percentage of digested nitrogen retained in the body	Percentage of total intake excreted in urine
	%	%	%
No. 2 Yellow corn + supplement	81	33	56
No. 2 N. wheat + supplement	84	31	60
Degermed shorts (1) + supplement	78	37	53
Degermed shorts (2) + supplement	78	35	51
Standard shorts + supplement	79	39	51

There may be a tendency for retention of a greater proportion of the digested nitrogen in shorts than is the case with corn or wheat. These differences between feeds in nitrogen utilization, however, are of little significance partly because the supplement was the main source of protein in all rations and partly because the availability of the dietary protein was undoubtedly affected by the relative laxative properties of the diets.

The division of crude protein into soluble and insoluble protein gave greater differences in digestibility between the two fractions where the total protein in the feedingstuff was higher. In corn where nearly one-third of the total protein was insoluble the digestibility of the insoluble was approximately the same as the soluble portion. In wheat (and the wheat products), in which the total protein was approximately double that of corn, the insoluble fraction represented one-seventh to one-ninth of the total protein and had correspondingly lower digestibility coefficients. Although the variability between animals (or periods) was considerably greater than that shown for dry matter digestibility coefficients it is reasonable to suppose that the soluble protein represents a fraction least affected by physical or chemical combination in the feed and hence more readily available to the animal organism. Conversely it may be expected that the insoluble fraction would give variable results depending on laxation, feed preparation, and amount of total protein.

In connection with Table 3 it is interesting to notice that the separation of carbohydrates into cellulose, soluble carbohydrates, and lignin, by the method of Crampton and Whiting has caused no significant change in the calculated total digestible nutrients. Close agreement exists in all the total digestible nutrient figures obtained by either method in spite of the highly variable lignin fraction in the new scheme.

CHEMICAL DESCRIPTION AS AN INDEX OF FEEDING VALUE

Although no appreciable differences in the digestibility or nutritive value of the standard and degermed shorts appears evident from the chemical composition and digestibility data so far presented it seems worthwhile to comment on the growth of the animals while on test. Table 5 shows

the average daily gains made by the animals on each of the four rations over the four trial periods. Thus each gain indicated represents all 4 pigs.

TABLE 5.—AVERAGE DAILY GAINS OF ANIMALS WHILE ON TEST

Ration	Average daily gain over four 15-day periods*	Total dig. nutrients**	
		Percentage in ration	Lb. eaten daily
	lb.		
No. 2 Yellow corn + supplement	1.18	83.3	3.31
No. 2 N. wheat + supplement	1.22	78.8	3.07
Degermed shorts + supplement	0.64	62.2	2.48
Standard shorts + supplement	1.14	62.5	2.41

* Includes the preliminary period of 5 days.

** On same moisture basis as in Table 2.

Since the response of the animals must remain the critical test of the true value of any feed this table of gains appears to indicate a deficiency in degermed shorts that was not made apparent by the chemical analysis. The fact that standard shorts gave nearly twice the daily gains of the degermed product is an important distinction between the two shorts samples. These data seem to bear out statements made previously that there is a tendency for wheat germ to stimulate, or facilitate, synthesis and deposition of body fat from dietary carbohydrate (3).

The failure of the crude fibre fraction to represent a biological or a chemical entity is clearly indicated in Table 2. The division of the crude fibre, in the case of standard shorts, into cellulose, lignin, and perhaps some carbohydrates, was different than in the case of the degermed shorts. The crude fibre digestibility coefficients were different; 16.9% for degermed shorts and 26.1% for standard shorts, whereas the cellulose coefficients were the same (14.5% and 14.7% respectively) showing that the crude fibre contained some highly variable constituents. The lignin digestibility coefficient for standard shorts was correspondingly higher than for degermed shorts thus compensating for the proportionately larger difference between crude fibre and cellulose coefficients.

The fraction called total digestible nutrients, which is determined from chemical composition modified by the digestibility coefficients gives undoubtedly valuable information in relation to any feedingstuff, but it gave a false estimation of the relative feeding values of the rations studied here. Standard shorts allowed gains almost equal to those of corn yet there was a difference of 20 percentage units in the total digestible nutrients values. Similarly the total digestible nutrient values of the two types of shorts offer no clue to the difference in animal response when it is known that the dry matter consumption was approximately equal for all feeds in each period.

These observations and criticisms of present feeding stuffs analyses seem to demand more informative methods of feed evaluation.

CONCLUSIONS

1. The digestibility of the chief energy yielding constituents of wheat and corn, namely protein, ether extract, and soluble carbohydrates are remarkably similar between the two feeds, as shown by swine digestibility trials.
2. Although the content and digestibility coefficients of the organic fractions of standard and of degermed shorts were quite similar, the growth rate of the animals while on test indicated superiority of the "standard" shorts.
3. Feed fractions constituting a small proportion of the ration are subject to proportionately greater error in digestibility trials than are the major fractions as indicated by negative digestibility coefficients for lignin-by-difference in corn and for crude fibre and cellulose in wheat.
4. The digestibility coefficients for the various feed fractions are sufficiently different from those determined with ruminants to warrant separate investigations with swine.

REFERENCES

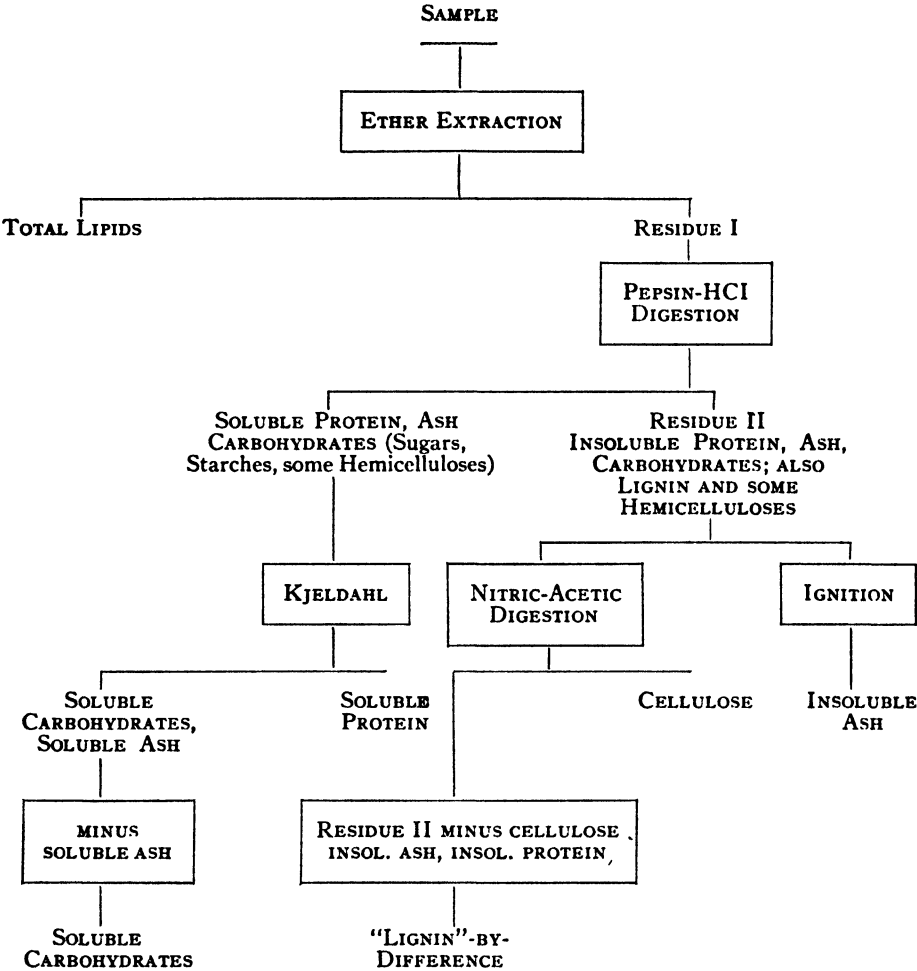
1. CRAMPTON, E. W., and F. WHITING. A proposed scheme of feedingstuffs analysis. *J. An. Sci.* 2: 4. 1942.
2. CRAMPTON, E. W. and F. WHITING. The digestibility of typical Eastern Canadian feeds by market bacon hogs. *Sci. Agric.* 23: 9. 1943.
3. CRAMPTON, E. W. and G. C. ASHTON. The effects of wheat germ and corn germ on the feeding value of cereal grains for hogs. *Sci. Agric.* 24: 2. 1943.

APPENDIX

DESCRIPTION OF FEEDS

- No. 2 Yellow Corn. The second grade of Eastern Canadian grown yellow corn. It was free of weed seeds and damaged kernels. The required quantity was ground to medium fineness and mixed with protein mineral supplement prior to first and third periods. A second lot was mixed for periods 3 and 4 owing to the rancidity of the first lot.
- No. 2 Northern Wheat. The third grade of Canadian Hard Red Spring wheat. Practically free of weed seeds. Ground and mixed prior to the commencement of the test.
- Standard Shorts. Consists of fine particles of bran, germ, and a small percentage of low grade flour as separated in the ordinary process of flour milling.
- Degermed Shorts. Two separate samples were obtained; one used throughout the test and the other used in the supplementary period. This product was similar to the standard shorts used except that it was a by-product of the Canada Approved flour hence was lower in wheat germ content.

Figure 1—DIAGRAMMATIC OUTLINE OF CRAMPTON AND WHITING SCHEME OF PROXIMATE PRINCIPLE FEED ANALYSIS



SOLUBLE ASH = TOTAL ASH (from separate sample) minus ASH of RESIDUE II.
INSOLUBLE PROTEIN = TOTAL PROTEIN (from separate sample) minus SOLUBLE PROTEIN.

INCREASE IN PRODUCTION AND VALUE OF THE WHEAT CROP IN MANITOBA AND EASTERN SASKATCHEWAN AS A RESULT OF THE INTRODUCTION OF RUST RESISTANT WHEAT VARIETIES¹

J. H. CRAIGIE²

Dominion Laboratory of Plant Pathology, Winnipeg, Manitoba

[Received for publication July 28, 1944]

INTRODUCTION

Does scientific research pay? In industry, this question has been answered very definitely in the affirmative. In agriculture, the same positive answer can be given by a great many farmers and others who have directly benefited from agricultural research. Probably if the public in general were more aware of the increase in the national income that may, and does, accrue from agricultural research, there would be a more insistent demand that ample financial support be provided for it. Broadly speaking, the prosecution of agricultural research is dependent on government support, and the support a government can provide for it is, in turn, largely dependent on the insistence of the public for such research and on the willingness of the taxpayers to supply funds for it. This insistence and willingness, in turn, will probably be directly proportional to the economic benefit that may accrue from the research, or rather in direct proportion to the awareness of the public in respect to that benefit.

In Canada, a large number of research projects in agriculture are now under way, but all, or practically all, of them are constantly hampered to a greater or less extent through lack of adequate financial support. There seems, therefore, to be an urgent need of bringing to the attention of the Canadian people concrete evidence of the benefit that has already accrued to them through agricultural research. The present paper gives such evidence in respect to one particular line of research, namely, the development of wheat varieties resistant to stem rust. In it, an estimate is given of the extent to which the general distribution of such varieties in Manitoba and eastern Saskatchewan, the "rust area" of Western Canada, has increased in these areas wheat production and, as a consequence, farm income.

Occurrence of Stem Rust

Previous to the distribution of rust resistant wheats in Manitoba and eastern Saskatchewan, stem rust, as has just been implied, was always more destructive in these two areas than in western Saskatchewan and in Alberta, although, in the latter areas, it caused a greater or less amount of damage in occasional years. It is known to have been present in Manitoba as

¹ Contribution No. 796 from the Division of Botany and Plant Pathology. Science Service, Dominion Department of Agriculture, Ottawa, Canada.

² Officer-in-Charge.

early as 1891, and probably was present considerably earlier. It did considerable damage, at least in Manitoba, in 1896, as it did also in 1902 and in 1903. It was epidemic in Manitoba and eastern Saskatchewan in 1904, and moderately severe in 1905. A heavy attack developed in parts of these two areas in 1911 and infection was prevalent in 1914. An epidemic of severe intensity broke out in 1916, and others followed in 1923, 1927, and 1935, and in 1938 (wherever rust resistant varieties were not grown). Attacks little short of epidemic intensity occurred in 1919, 1921, 1925, and 1930. In 1937, stem rust was of moderate to severe intensity in Manitoba, except along the western margin of the province where—as well as in the greater part of Saskatchewan—severe drought conditions caused a complete crop failure. In the remaining years from 1900 onward to 1939, the first year in which varieties of wheat resistant to stem rust were widely grown throughout the “rust area” of Western Canada, the severity of infection varied from light to moderate. Had not rust resistant wheat varieties been distributed in this area (and in the northern Mississippi Valley as well), it is probable that stem rust would have continued to recur and be as destructive there as it formerly had been.

Figure 1 indicates the approximate western boundary of severe stem rust damage in 1935 and 1938. In 1916 and 1927, the area of severe damage extended somewhat further westward than in 1935 or 1938; in 1923, it did not extend as far as in either of these years. That is to say, the area severely affected by stem rust varied considerably in size from one epidemic year to another.

Losses from Stem Rust

The bulk of the loss from stem rust in Western Canada has occurred in Manitoba and eastern Saskatchewan, although substantial loss has occurred in occasional years in western Saskatchewan and Alberta. The loss from stem rust in wheat, to say nothing of the loss in oats and in barley, has been enormous. It is generally agreed that in 1916 the loss in wheat in Western Canada amounted to 100,000,000 bushels (2, 3). In 1927, it was calculated to be about 90,000,000 and in 1935, over 87,000,000 bushels (4). For the 11-year period 1925-1935, the average annual loss in Manitoba and Saskatchewan was calculated to be 35,518,000 bushels, constituting a cash loss through reduction in yield alone of \$30,784,000 each year of this period (4).

Not only does stem rust greatly reduce production, but it also causes a pronounced reduction in the quality, and hence in the grade, of the grain, which reduction, in turn, is reflected in a reduced market price. The rusted wheat crop of 1916 may be taken to illustrate these two sources of loss. On the supposition that no loss from stem rust had occurred in that year, an additional 100,000,000 bushels of wheat would have been available for consumption. It is fair to assume that practically all of this wheat would have fallen within the grades No. 1 to No. 4 Northern. From October, 1916, to March, 1917—during which period most of the grain would have

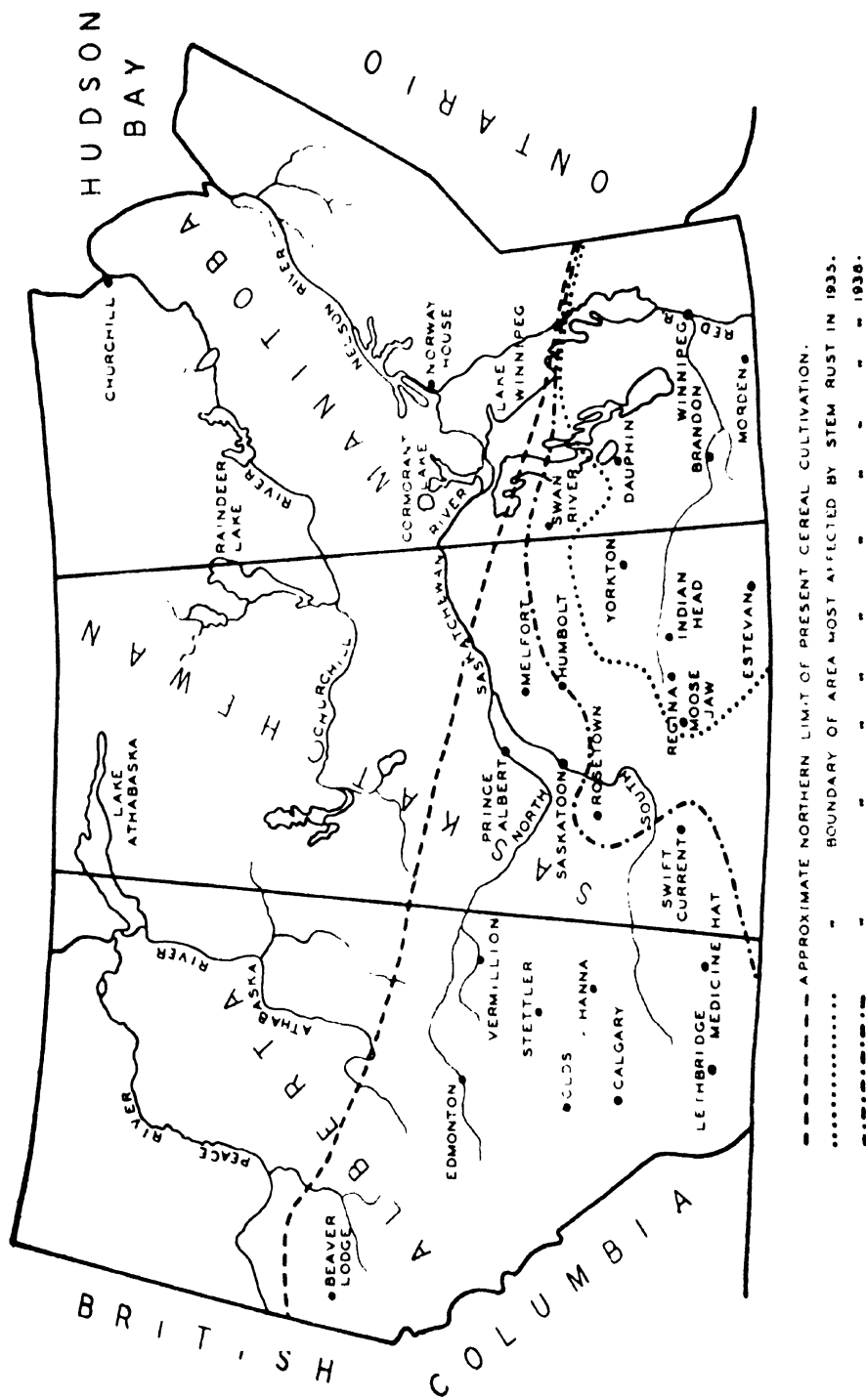


FIGURE 1. Map of Western Canada, showing the approximate boundary of the area most affected by stem rust in 1935 and 1938.

probably been sold off the farm—the average price at Winnipeg, Man., for these grades of wheat were, respectively, about \$1.75, \$1.72, \$1.70, and \$1.59 (Canada Year Book, 1918). In the following four months, the price of wheat soared very much higher; only in one of these months (April) did the monthly average for No. 4 Northern fall below \$2.00 per bushel. If \$1.70 per bushel be taken as the average price for the 100,000,000 bushels that were not produced, it is evident that the monetary loss from this source was \$170,000,000, although, in view of the higher price prevailing after March, the actual loss may have been considerably higher.

To this loss there must be added the loss due to reduction in grade of the wheat that was produced. As, in 1916, the damage from stem rust was not pronounced in Alberta, it may be assumed that the loss due to reduction in grade occurred entirely in Manitoba and Saskatchewan. In that year, the wheat production in Manitoba amounted to about 27,400,000 and, in Saskatchewan, to about 121,800,000 bushels, making a total of approximately 149,200,000 bushels. Again, on the supposition that no stem rust damage had occurred and that most of this wheat would have fallen within the grades No. 1, 2, 3, or 4 Northern, the value of the crop would have been (at \$1.70 per bushel) in the vicinity of \$253,640,000. Owing to the reduction in the grade of the grain, however, the average price per bushel received for the Manitoba wheat was \$1.23 and for the Saskatchewan wheat, \$1.28 per bushel. It can readily be calculated, therefore, that the actual farm income from the wheat crop in these two provinces was \$189,606,000. Thus the loss due to reduction in grade was \$253,640,000 less \$189,606,000, or \$64,034,000.

Owing therefore to the ravages of stem rust in Western Canada in 1916, there was a loss of \$170,000,000 from reduction in wheat production and of \$64,034,000 from reduction in grade, thus making a total monetary loss of \$234,034,000. Bailey (1) estimated the loss at \$200,000,000. According to the above calculation, his estimate was sufficiently conservative.

Although, in the foregoing paragraphs, the discussion is confined to damage from stem rust of wheat, it should be mentioned that leaf rust of wheat has been present every year in Western Canada and in occasional years did considerable damage, especially in Manitoba and the more easterly portion of Saskatchewan. Before varieties of wheat resistant to stem rust were distributed, the preponderant amount of rust damage was unquestionably caused by stem rust. The distribution of these varieties has, however, only partially eliminated damage from leaf rust, as, of the four rust resistant varieties now grown (Thatcher³, Regent, Renown, and Apex), only two are resistant to leaf rust. In fact, the variety most widely grown in Manitoba and eastern Saskatchewan is highly susceptible to this rust. If all of the four rust resistant varieties now grown were resistant to leaf rust as well

³ A variety developed by Dr. H. K. Hayes of the University of Minnesota, U.S.A.

as to stem rust, the increase in wheat production brought about by the distribution of them in Manitoba and eastern Saskatchewan would be slightly greater than that indicated subsequently in this paper.

Rust Resistant Wheats Distributed

The distribution of rust resistant wheats was begun on a small scale in Manitoba in 1936, and by 1938 slightly more than one-half of the wheat acreage in this province was sown to such wheats. In the latter year, approximately 30% of the wheat acreage was sown to durum wheat varieties. As the durum wheats grown are partially resistant to stem rust, the year 1938 may be taken as the first year in which resistant varieties were widely grown in Manitoba. (In passing, it may be mentioned that, had it not been for the rapid increase in durum production after the epidemic of 1923, the loss from stem rust in Manitoba from that year to 1937 would have been much greater than indicated in this paper). As mentioned earlier, stem rust was epidemic in 1938 on susceptible wheats in Manitoba as well as in eastern Saskatchewan, and much heavier infection than usual was present in western Saskatchewan and in Alberta. Owing to a scarcity of seed of the resistant varieties, distribution of them in eastern Saskatchewan was somewhat less rapid than in Manitoba, so that it was not until 1939 that rust resistant varieties became widely grown in that area. The years 1938 and 1939 may, therefore, be regarded, respectively, as the first years in which the growing of rust resistant wheats definitely influenced wheat production in Manitoba and eastern Saskatchewan.

COMPARISON OF THE YIELD OF MARQUIS WHEAT AND FOUR RUST RESISTANT WHEATS IN THE PRESENCE OF RUST

By way of illustrating the superiority in yielding ability, in the presence of rust attack, of the rust resistant wheats now being widely grown in the "rust area" of Western Canada over rust susceptible wheats that were formerly grown in this area, data are given in Table 1 on the yield of Thatcher, Regent, Renown, and Apex, four rust resistant varieties, and of Marquis, a rust susceptible variety formerly very extensively grown in this area. These data are taken from the Co-operative Test Reports of the Sub-Committee on Plant Breeding, Associate Committee on Field Crop Diseases, National Research Council and Dominion Department of Agriculture, and are based on the yields of adequately replicated rod rows grown at four Stations in Manitoba in 1935, 1938, and 1940. On susceptible varieties, rust was extremely severe in 1935, severe to moderately severe in 1938, and comparatively light in 1940. In each of these years, the severity of infection varied somewhat from Station to Station, the infection being regularly more severe at Winnipeg, where the naturally-occurring infection was intensified by an artificially-induced infection. In respect to plant growth, Marquis as well as Thatcher, Regent, and Renown are well adapted to Manitoba conditions. Apex, on the other hand, is not generally so well adapted to these conditions as are the other four varieties, a fact that largely accounts for its yield being usually somewhat lower than that of the other three resistant varieties.

TABLE 1.—COMPARISON OF THE EFFECT OF RUST ON THE YIELD PER ACRE OF THE WHEAT VARIETIES MARQUIS, THATCHER, RENOWN, REGENT, AND APEX AT FOUR STATIONS IN MANITOBA IN 1935, 1938, AND 1940

(Based on the yield of replicated rod row plots)

Stations	Wheat varieties				
	Marquis	Thatcher	Regent	Renown	Apex
	bu.	bu.	bu.	bu.	bu.
1935					
Morden	5.5	32.9	27.4	21.9	17.5
Winnipeg	1.9	21.8	21.1	21.2	12.3
Brandon	8.8	43.5	40.3	37.8	30.2
Gilbert Plains	1.7	26.5	30.7	25.6	18.4
Average	4.5	31.2	29.9	26.6	19.6
1938					
Morden	17.6	30.4	38.4	33.0	32.8
Winnipeg	5.0	18.1	25.7	20.2	17.6
Brandon	15.6	45.7	48.9	47.5	44.6
Gilbert Plains	21.2	30.8	30.5	32.4	30.0
Average	14.8	31.2	35.9	33.3	31.2
1940					
Morden	23.7	44.5	45.6	41.1	39.4
Winnipeg	12.7	43.4	41.0	42.4	34.0
Brandon	32.5	39.1	40.2	37.8	37.9
Gilbert Plains	40.3	37.3	37.3	31.7	33.3
Average	27.3	41.1	41.0	38.2	36.1

It is evident from Table 1 that, in 1935, the average yield of Marquis was extremely low, whereas that of the resistant varieties was from 4 to 7 times higher. In 1938, owing to the comparatively late date at which rust became severe on susceptible wheats in Manitoba, the damage to such varieties was considerably less pronounced than in 1935. Despite this ameliorative circumstance, the average yield of the resistant varieties was more than double that of Marquis. Even in 1940, a relatively light rust year, the resistant varieties out-yielded Marquis, except at Gilbert Plains, by a considerable amount. The marked disparity between the yield of these varieties and that of Marquis in 1935 and 1938, and at Winnipeg and Morden in 1940, is almost entirely attributable to injury suffered by Marquis from rust. In the absence of rust injury, Marquis would have approximated the resistant varieties in respect to yield, or even might have occasionally surpassed them, as it did at Gilbert Plains in 1940. Consequently, over a period of years in which wide variation from season to season occurred in the amount of injury caused by rust, the disparity between the average yield of rust susceptible and rust resistant wheats has been much less pronounced than that just indicated.

IMPROVEMENT IN WHEAT PRODUCTION AND VALUE RESULTING FROM THE GROWING OF RUST RESISTANT VARIETIES

In order to gain some idea of what economic benefit rust resistant wheats have been to wheat producers in Manitoba and eastern Saskatchewan—and indirectly to everyone in Canada—a comparison may be made of the actual wheat production in these two areas during the years in

which rust resistant varieties were widely grown, and what the production in these two areas would probably have been during the same years if rust resistant varieties had not been grown. The difference between the actual production (when rust resistant varieties were grown) and the probable production (had such varieties not been grown) will indicate, for each area, the increase in production that has accrued as a result of the introduction of rust resistant wheats. From this difference, the monetary improvement in farm income arising from the increased production can be calculated. The computation, of course, disregards entirely the improvement in yield and value of the wheat crop in other parts of Canada where rust resistant varieties have been introduced.

Attention should be directed to the fact that the improvement in wheat production resulting from the growing of rust resistant wheats is largely, but not entirely, attributable to the control of stem rust effected by these wheats. It is known that, even in the absence of stem rust, the rust resistant varieties tend to out-yield Marquis wheat, the variety most widely grown in Western Canada prior to the introduction of rust resistant ones. In the following computations, no attempt has been made to differentiate between the increased production attributable to this factor and that attributable to the control of stem rust, as both sources of increase are directly attributable to the development and distribution of rust resistant wheats.

The data relative to acreage, actual production and actual value for Manitoba and eastern Saskatchewan, as well as the data on which the probable production is based, were taken, respectively, from the annual crop report bulletins of the Manitoba Department of Agriculture and the annual reports of the Saskatchewan Department of Agriculture. From these two sources and The Canada Year Book were taken the data relative to price per bushel.

Improvement in Manitoba.

A comparison is given in Table 2 of the actual wheat production in Manitoba during the 6 years 1938 to 1943 - the period in which varieties of wheat resistant to stem rust were largely grown--and the probable production (had susceptible varieties continued to be grown). The probable production in each of these years is based on the acreage sown to wheat in each of the 6 years and the average yield per acre for 16 previous years, namely, 1916-1928, 1930, 1935, and 1937. The years 1929, 1931-1934, and 1936 are omitted, because, in these years, pronounced drought in some parts of the province markedly reduced the yield. The omission of these years helps to eliminate drought as a factor influencing the average yield per acre. Although during the period 1917 to 1921, drought or partial drought conditions prevailed in some parts of the province, any influence that these conditions may have on this average is probably more than sufficiently off-set by similar conditions in parts of the province in the years 1939, 1940, and 1941

TABLE 2.—COMPARISON OF (A) THE ACTUAL WHEAT PRODUCTION (WHEN RUST RESISTANT VARIETIES WERE GROWN) AND (B) THE PROBABLE WHEAT PRODUCTION (IF RUST RESISTANT VARIETIES HAD NOT BEEN GROWN) IN MANITOBA DURING THE 6-YEAR PERIOD 1938-1943

Year	Total acrage sown	A		B		Difference in production
		Actual production	Probable yield per acre ¹	Probable production		
	(000)	(bu.) (000)	(bu.)	(bu.) (000)	(bu.) (000)	
1938	3,184	50,000	15.15	48,253	1,747	
1939	3,201	61,300	15.15	48,495	12,805	
1940	3,512	66,400	15.15	53,206	13,194	
1941	2,442	51,000	15.15	36,996	14,004	
1942	1,930	53,650	15.15	29,239	24,411	
1943	1,640	41,000	—	24,846	16,154	
Total	15,909	323,350	—	241,035	82,315	
6-year average	2,651	53,891	—	40,172	13,719	

¹ Average yield for the 16 years 1916-1928, 1930, 1935, and 1937.

The difference, therefore, between the actual production of wheat in the province during the 6 years 1938-1943, in which varieties of wheat resistant to stem rust were largely grown, and the production that would have probably been obtained if susceptible varieties had continued to be grown in these years, may logically be attributed to the growing of rust resistant varieties of wheat. It will be seen in Table 2 that this difference in wheat production for the 6-year period amounts to 82,315,000 bushels, or to an annual average difference of 13,719,000 bushels. The average annual wheat acreage in Manitoba was 2,651,000 acres, so that the average difference in yield per acre between the actual production and the probable production is 5.17 bushels.

This increase in wheat production has very materially improved farm income in this province. Table 3 gives the actual value of the wheat crop in these 6 years and the probable value of that crop if rust resistant wheat varieties had not been grown. The probable value given is very likely somewhat higher than it should be, as it is based on the price per bushel obtained in each respective year for Manitoba-produced wheat that was not damaged by rust. If rust resistant wheats had not been grown, there would have probably been considerable rust damage in some of these 6 years, and consequently, owing to a lowering of the grade in any such year, the average price per bushel would have been somewhat less than that given in this table. On the basis of the average price per bushel, the difference between the two values is \$57,505,000, or an annual difference of \$9,584,000. In other words, the farm income of Manitoba was increased by this amount in each of the 6 years.

TABLE 3.—COMPARISON OF (A) THE ACTUAL VALUE OF THE WHEAT CROP (WHEN RUST RESISTANT VARIETIES WERE GROWN) AND (B) THE PROBABLE VALUE OF THE CROP (IF RUST RESISTANT VARIETIES HAD NOT BEEN GROWN) IN MANITOBA DURING THE 6-YEAR PERIOD 1938-1943

Year	Average price per bushel	A	B		Difference in value
		Actual value	Probable production	Probable value	
		(000)	(bu.) (000)	(000)	(000)
1938	\$0.61	\$30,500	48,253	\$29,434	\$ 1,066
1939	0.55	33,715	48,495	26,272	7,443
1940	0.53	35,192	53,206	28,199	6,993
1941	0.51	26,010	36,996	18,868	7,142
1942	0.72	38,628	29,239	21,052	17,576
1943	1.07	43,870	24,846	26,585	17,285
Total	—	207,915	—	150,410	57,505
6-year average	—	34,652	—	25,068	9,584

Perhaps it would be of interest to gain an idea of how much loss this province suffered in wheat production and in farm income through the lack of suitable rust resistant wheat varieties during the 16 years referred to above. It is realized that, during these years, an increased production would have probably lowered the price of wheat, but any fall in the price of wheat as a result of higher production in these years would have been largely off-set by a fall in price due to loss of grade resulting from damage by rust. The total acreage sown to wheat in these years was 43,707,100 acres, and it has been shown above that the rust resistant wheats out-yielded susceptible wheats by 5.17 bushels per acre. Had resistant wheats been grown during these 16 years, they would have probably out-yielded the susceptible wheats by an equal amount per acre. The total loss in these 16 years was, therefore, probably in the vicinity of 225,965,000 bushels, or an average annual loss of approximately 14,123,000 bushels. The average price of Manitoba-produced wheat for these years was approximately \$1.19 per bushel, so that the total monetary loss was about \$268,898,000, or an annual loss of \$16,806,000.

Improvement in Eastern Saskatchewan

As pointed out earlier, stem rust has usually been somewhat less destructive in eastern Saskatchewan than in Manitoba, but the total acreage of wheat is very much greater in the former than in the latter area, and hence, over a period of years, the aggregate loss in production and value of the crop through damage from stem rust would be expected to be greater. For the purpose of the present computation, eastern Saskatchewan is taken to include the following six crop districts: No. 1 (South-Eastern), No. 2 (Weyburn-Regina), No. 3 (South-Central), No. 5 (East-Central), No. 6 (Central), and No. 8 (North-Eastern). Actually, only the

eastern half of No. 3 and of No. 6 lie within the "rust area", but, as production data for these two halves are not available, it is necessary to regard both districts as lying wholly within that area.

In Table 4 is given a comparison of the total actual wheat production in eastern Saskatchewan during the 5-year period 1939-1943—a period during which rust resistant varieties of wheat were extensively grown—and the total probable wheat production in these years if rust resistant varieties had not been grown. The data are given by crop districts, but to conserve space, only the totals for the 5 years are presented. The total probable production in any given district is calculated from the total acreage sown to wheat in that district during the 5 years and the average yield per acre obtained in that district during 16 years (1916-1928, 1930, 1935, and 1938) in which rust susceptible varieties were largely grown. (Drought caused a complete crop failure in eastern Saskatchewan in 1937, and hence the substitution of 1938 for 1937, although in 1938 probably about one-quarter of this area was sown to rust resistant wheats). Table 4 shows that, for the six crop districts, the total actual wheat production exceeds the total probable wheat production by 138,101,000 bushels. In other words, the growing of rust resistant wheats in these 5 years increased the total production by that amount, or by an average of 27,620,000 bushels per year.

TABLE 4.—COMPARISON OF (A) THE TOTAL WHEAT PRODUCTION (WHEN RUST RESISTANT VARIETIES WERE GROWN) AND (B) THE TOTAL PROBABLE WHEAT PRODUCTION (IF RUST RESISTANT VARIETIES HAD NOT BEEN GROWN) IN SIX CROP DISTRICTS IN EASTERN SASKATCHEWAN DURING THE 5-YEAR PERIOD 1939-1943

Crop District	Total acreage sown	A		B		Difference in production
		Actual production	Probable yield per acre ¹	Probable production		
	(000)	(bu.) (000)	(bu.)	(bu.) (000)	(000)	
No. 1	3,707	67,643	13.80	51,104	16,539	
No. 2	7,306	123,396	14.72	107,544	15,852	
No. 3	14,899	255,220	14.74	219,611	35,609	
No. 5	5,977	124,797	17.20	102,804	21,993	
No. 6	10,013	170,305	14.04	140,583	29,722	
No. 8	3,951	94,917	19.37	76,531	18,386	
Total	45,853	836,290	—	698,177	138,101	
5-year average	9,170	167,258	—	139,635	27,620	

¹ Average yield per acre for the 16 years 1916-1928, 1930, 1935, and 1938 in the respective crop districts.

The improvement in farm income in eastern Saskatchewan resulting from the introduction of rust resistant wheats is indicated in Table 5. This table gives, for each of the 5 years, the actual value of the wheat produced in the six crop districts, and the probable value of the wheat that would have been produced in them if rust susceptible varieties had continued to be grown during these 5 years. The price per bushel in any given year is the average price per bushel obtained in that year for wheat pro-

duced in Saskatchewan as a whole. As pointed out earlier in connection with a similar computation for Manitoba, the probable value is very likely over-estimated, for, if rust susceptible varieties had been grown, the price per bushel received, owing to a reduction in the grade of the wheat, would probably have been somewhat less in some of the years than that indicated. According to these calculations, the actual value of the wheat produced during the 5 years is \$88,293,000 in excess of the probable value for these years. In other words, the farm income in eastern Saskatchewan was increased on an average by \$17,658,000 each year.

TABLE 5.—COMPARISON OF (A) THE ACTUAL VALUE OF THE WHEAT CROP (WHEN RUST RESISTANT VARIETIES WERE GROWN) AND (B) THE PROBABLE VALUE OF THE CROP (IF RUST RESISTANT WHEAT VARIETIES HAD NOT BEEN GROWN) IN SIX CROP DISTRICTS OF EASTERN SASKATCHEWAN DURING THE 5-YEAR PERIOD 1939-1943

Year	Average price per bushel	A	B		Difference in value
		Actual value	Probable production	Probable value	
		(000)	(bu.) (000)	(000)	(000)
1939	\$0.54	\$100,122	152,221	\$82,119	\$18,003
1940	0.53	92,538	166,078	88,021	4,517
1941	0.53	56,498	130,975	69,417	(-) 12,919
1942	0.65	157,521	135,399	88,009	69,512
1943	1.03	131,159	118,427	121,979	9,180
Total	---	537,838	—	449,545	88,293
5-year average	—	107,567	—	89,909	17.658

During the 16 years 1916-1928, 1930, 1935, and 1938, eastern Saskatchewan sustained a pronounced monetary loss through the lack of suitable rust resistant varieties of wheat. An estimate of what this loss has been can be arrived at by a simple calculation. In Table 4 it is shown that, for the 5-year period, the average annual acreage sown was 9,170,000 acres and the average annual difference between the actual production and the probable production was 27,620,000 bushels. It is evident, therefore, that rust resistant wheats yielded on an average 3.0 bushels more per acre than susceptible wheats would have yielded had they been grown. The total wheat acreage in the six crop districts for the 16 years was 143,351,000 acres. On the supposition that rust resistant varieties had been grown during these 16 years, the production of wheat would have been increased by 430,053,000 bushels, or approximately 26,878,000 bushels each year. That is to say, there was an annual loss in wheat production equal to this amount. For these 16 years, the average price of wheat produced in Saskatchewan was \$1.14 per bushel—a much higher average price than prevailed from 1939 to 1943—so that, for these 16 years, the total loss was somewhere about \$490,260,000, or a loss of \$30,641,000 each year.

DISCUSSION

It is evident from the foregoing discussion that the development of rust resistant wheats and their general introduction in the bad rust area of Western Canada has been of immense financial benefit to wheat growers in that area, and indirectly in greater or less degree to everyone in Canada. Such varieties have also been introduced in other parts of Canada, and, to the extent that stem rust has been destructive in those parts, to that extent has the value of the wheat crop in those parts been increased.

Not only has the development of rust resistant wheats been of immense financial benefit to everyone concerned, but it has been of decided benefit to the morale of the farmers themselves and of the public in general. It has removed one of the worst wheat crop hazards. The farmer now has confidence, that, barring insect damage, and drought, hail, or other crop hazard over which he has no control, a crop will reward his labours. The public is assured of an adequate wheat supply and of more stable economic conditions.

Furthermore, there seems to be good evidence that similar benefits, even if less pronounced, have accrued in respect to the production of barley in Western Canada, particularly in the "rust area." Wheat stem rust attacks barley as well as wheat, that is to say, it attacks susceptible varieties of both crops. The extensive growing of rust resistant wheats in Manitoba and eastern Saskatchewan (and in the northern Mississippi Valley as well) has enormously reduced the amount of stem rust inoculum (red spores) available for the spread of stem rust from wheat to barley. As a result of this decrease in the amount of inoculum, a great deal less infection than formerly has developed in the last four or five years on barley, especially on late sown barley. This circumstance, in turn, has improved the income of barley growers in this area, and, thereby, has improved the national income. Unfortunately, however, the danger of rust damage to barley has not been entirely removed. To overcome this danger completely, rust resistant varieties of barley must be developed.

As, under ordinary field conditions, wheat stem rust does not attack oats, the growing of rust resistant wheats has not had a corresponding effect on the amount of stem rust infection on oats. In this connection, it may be said that oat varieties highly resistant to the races of oat stem rust that have in past years been prevalent in Canada, have been produced and are now rather widely distributed. The improvement in farm income from this source itself has been substantial.

In comparison with the loss that formerly occurred from damage to wheat by stem rust, the cost of rust research in Canada has been so small that it is scarcely worthy of mention. It is safe to say that from 1916—prior to that apparently nothing was spent—up to the present, the total amount expended in Canada by governments, institutions, and other organizations, all combined, did not exceed \$2,000,000. In fact, the amount was probably a good deal less. The present computations show that the development and introduction of rust resistant wheats have increased the average annual value of the wheat crop in Manitoba and eastern Saskatchewan, respectively, \$9,584,000 and \$17,658,000, or a combined increase

of \$27,242,000. In other words, since the advent of rust resistant wheats, the improvement in farm income in these two areas would, on an average, repay in a single year more than thirteen times over all the expenditure ever made by Canada on wheat rust research. (If the average price per bushel had been as high for wheat during the last 5 years as it was in the 16 earlier years discussed in this paper, the annual improvement in farm income would have repaid the expenditure on wheat rust research more than twenty-three times over).

As indicated in the introduction, the scope of this paper is strictly limited, and no digression into a general discussion of the advantages that have accrued already, or may accrue in future, from other lines of scientific agricultural research is admissible here. One point, however, may be mentioned. If Canada is to maintain a high export level of farm products, and particularly if she must continue to compete in respect to these products in world markets, it is absolutely essential that production costs of farm products in Canada be reduced. To accomplish this, the productive capacity of the various factors involved in farm production must be increased. There is little question that this can be accomplished through concentrated scientific research, and through it alone can it be accomplished at minimum cost.

SUMMARY

An estimate is given of the increase in wheat production and of the resulting increase in farm income from this source that have accrued through the development and introduction of wheat varieties resistant to stem rust. It is shown that, in Manitoba for the 6-year period 1938-1943, the actual average annual production and value of the wheat crop exceeded the probable average annual production and value—had rust susceptible varieties continued to be grown during these years—by 13,719,000 bushels and \$9,584,000, respectively. In eastern Saskatchewan, for the 5-year period 1939-1943, the corresponding figures are 27,620,000 bushels and \$17,658,000. That is to say, the growing of rust resistant wheat varieties in these two areas has increased, respectively, the average annual wheat production and farm income in the "rust area" of Western Canada by 41,339,000 bushels and \$27,242,000.

It is estimated that, if the present rust resistant varieties of wheat had been grown in Manitoba in the 16 years 1916-1928, 1930, 1935, and 1937, the yield per acre would have exceeded that obtained from the rust susceptible varieties that were grown in those years by 5.17 bushels. In other words, the average annual loss in wheat production for these 16 years was about 14,123,000 bushels, and in farm income, \$16,806,000. Similarly, in eastern Saskatchewan, if the present rust resistant varieties had been grown in the 16 years 1916-28, 1930, 1935, and 1938, the average yield per acre would have been increased by 3.0 bushels, with a consequent annual increase in wheat production of 26,878,000 bushels, and in farm income

of \$30,641,000. The total annual monetary loss in the "rust area" of Western Canada for these 16 years was, therefore, in the neighbourhood of \$47,447,000.

Furthermore, it is estimated that, in the 5-year period 1939-1943, the average annual increase (\$27,242,000) in farm income accruing from the growing of rust resistant wheats in Manitoba and eastern Saskatchewan would repay more than thirteen times over the total expenditure made by Canada on wheat rust research.

REFERENCES

1. BAILEY, D. L. Studies in cereal diseases. IV. Stem rust in Western Canada. Dom. Dept. of Agric. Bull. 106-N.S. 1928.
2. BULLER, A. H. R. Essays on wheat, pp. 1-339. The McMillan Company, New York. 1919.
3. FRASER, W. P. The outbreak of wheat rust in 1916. Month. Bull. Agric. Statist. Dept. Trade and Commerce, Ottawa, Canada, 11 : 61-67. 1918.
4. GREANEY, F. J. Cereal rust losses in Western Canada. Sci. Agric. 16 : 608-613. 1936.

A DISEASE OF THE EUROPEAN SPRUCE SAWFLY, *GILPINIA HERCYNIAE* (HTG.), AND ITS PLACE IN NATURAL CONTROL¹

R. E. BALCH² AND F. T. BIRD³

Dominion Entomological Laboratory, Fredericton, N.B.

[Received for publication July 15, 1944]

The European spruce sawfly, *Gilpinia hercyniae* (Htg.), was apparently introduced to Canada at least several decades ago (1). When first discovered in 1930, a large outbreak had already developed. The history of this outbreak has been described (2, 3). It reached its peak about 1938, when some 12,000 square miles were estimated as being heavily infested. During the next few years the numbers of the insect declined, until by 1943 no important defoliation was being caused.

The decline of the outbreak coincided with the appearance of high percentages of larval mortality due to disease. This paper will discuss the evidence that the disease was responsible for the decline of the outbreak. It will also give some preliminary information regarding the nature of the disease pending the completion of further experimental studies to be reported in full later by the junior author.

HISTORY OF DISEASE

The first evidence of a disease affecting the sawfly was obtained in the laboratory in 1936. During 1934 and 1935 continuous rearings of pure lines of the insect had been carried on by Mr. C. C. Smith for as many as twenty-five generations, without any sign of disease. Early in 1936, small percentages of the larvae began to die. The amount of mortality increased steadily until by 1939 it had become impossible to rear a single larva in the laboratory by ordinary methods.

In the forest only rare individuals which might have been diseased were observed until 1938. During the latter part of this year diseased larvae became numerous in some parts of New Brunswick and were noted by Dowden (8) in heavily infested areas in Vermont and New Hampshire. In 1939 mortality was high at these points and was observed over much wider areas. In 1940 Dowden concluded that the disease was responsible for controlling the outbreaks in Vermont and New Hampshire. The same year Peirson (11) reported that it was prevalent in parts of Maine, but did not consider it a reliable factor of control.

In Canada, from 1939 to 1942 the epidemic appeared to spread from south to north. Disease was not evident on this laboratory's plots in central Gaspé, Quebec, until 1940 and did not cause any striking reduction in population there until 1942. The first report of its occurrence on the north shore of the St. Lawrence was in 1940 (5). By 1942, however, it was known to be distributed throughout the greater part of the range of the sawfly. Samples of larvae collected from numerous localities scattered from Nova Scotia to Lake Ontario have shown both the external and internal symptoms.

¹ Contribution No. 2320, Division of Entomology, Science Service, Department of Agriculture, Ottawa, Canada.

² Officer-in-charge.

³ Agricultural Assistant.

The disease was first noticed in heavily infested areas but has been found since causing considerable mortality in light infestations. Since 1940 the authors have never failed to find it wherever the sawfly has been moderately numerous. It has also been prevalent in stands which have never been more than lightly infested, and were in some cases over 100 miles from the nearest heavy infestation. Dr. C. E. Atwood and Mr. K. E. Stewart, of this Division, however, have reported on areas in Ontario which were apparently still free from the disease in 1942. No evidence has been found of its presence in Newfoundland. These areas are the farthest removed from the main heavily infested region. It appears that a high density of host population may have been necessary, or favourable, to the development of the epidemic, but that it rapidly achieved a momentum which carried it long distances more or less regardless of the density of the population of the host. In 1943 it was still causing considerable mortality in lightly infested stands.

There is no definite evidence regarding the origin of the disease. It is not improbable that it was introduced to this continent from Europe with parasite material. Dr. W. R. Thompson of the Imperial Parasite Service has kindly supplied information regarding a study of a disease of *Gilpinia polytoma* (Htg.), made during the course of parasite investigations in Europe, which strongly suggests that it is the same as the disease in Canada. Dr. K. R. S. Morris has also reported a disease attacking this species in central Europe. Apparently, *Gilpinia pallida* (Klug.), *Diprion pini* (Shrank) and *Neodiprion sertifer* (Geoff.) are affected by the same disease.

VALUE AS A CONTROL FACTOR

Natural Control Before Disease Appeared

In order to estimate the effect of a new factor of control it is necessary to know something of the nature of the control complex before this factor was added.

Since 1930 the Fredericton laboratory has studied the population of the sawfly and the factors controlling it (3). Most of the data have been obtained from seven plots in Quebec and New Brunswick. On all of these for periods of from 4 to 8 years the cocoon population has been estimated annually by a method of sampling which has been described by Prebble (13). On four of them the larvae dropping from the trees have also been recorded daily for a number of years. This was accomplished by means of trays, corresponding in size and method of location under the trees to the ground quadrates used for cocoon sampling (10). Random samples of larvae and cocoons have also been taken periodically from numerous points throughout the Maritime Provinces and the Gaspé area. Through the Forest Insect Survey, 5,865 collections of larvae and 1,202 collections of cocoons have been received and analyzed at Fredericton. Each year studies have been made of adult emergence, oviposition, and egg mortality. The various factors of natural control have been investigated by laboratory and field experiments. Although it is difficult with this insect to obtain satisfactory estimates of the population in the adult and egg stages, the above work has provided a fairly complete picture of the progress of the outbreak and the factors determining local and general population trends.

Some of the results have been published (2, 3, 9, 12, 14). The following is an attempt to summarize them for the period preceding the appearance of disease.

The sawfly had evidently increased rapidly in the Gaspé for some years prior to its discovery in 1930. Between 1930 and 1938 the area of heavy infestation spread over most of the peninsula, and heavy infestations developed throughout New Brunswick, in northern Maine, in parts of Vermont and New Hampshire, and to the west of the Gaspé in Quebec. At the same time moderate or light infestations occurred through all other parts of the spruce forests of this region and extended from Nova Scotia to the north shore of the St. Lawrence and west to Ontario.

The rate of increase during this time was irregular, owing chiefly to annual and regional fluctuations in the percentage of eonymphs remaining in diapause in the cocoon (12). Higher percentages of diapause caused lower populations of feeding larvae, increased cocoon mortality, and checked the rate of increase. The cocoon population, however, tended to rise, irregularly but persistently, until limited by the supply of foliage. It was evident that although many control factors were operating on the sawfly, the survival rate in the main types of spruce forest was sufficient to bring about an increase in its numbers until the upward population trend was reversed by a shortage of food. Owing to the reserve of cocoons in diapause, and to the reluctance of the larvae to eat the new foliage this drop in numbers was generally rather gradual, and during the process the defoliation of the trees was often completed. Toward the south, however, diapause tendency was low and population fluctuations were more violent.

The factors controlling the rate of increase have varied somewhat in relative importance in different seasons, regions and forest types. They have been, however, much the same in all the places studied and in a general way may be summarized by stages as follows:

The Egg. No natural enemies of the egg have been found and no important mortality has resulted from climatic factors. Some are lost through the drying and dropping of needles in which they are laid. The percentage hatch has generally been over 90 and close to 95.

The Larva. The feeding larval stages are well adapted to the climatic conditions under which spruce grows. A small percentage of the first instar dies from rain and unknown causes. The larvae are resistant to several degrees of frost but in cool seasons some mature too late to reach the cocoon stage before winter. A number of the immature larvae drop from the trees but many of these crawl back to the foliage. Birds and insect predators take a moderate toll of all instars, but, as shown by Reeks (14), native parasites have accounted for no more than 0.02%. Shortage of food in the later stages of outbreaks has been the cause of the greatest amount of larval mortality.

The Cocoon. In the dormant condition in the cocoon the sawfly will survive temperatures lower than any experienced in the forest floor. It is also resistant to the effects of extreme dry or wet weather, although some mortality results from prolonged wet conditions on poorly drained sites. Dry weather may cause mortality indirectly by prolonging diapause and thus increasing length of exposure to predators (12). The greatest

mortality in the cocoon is caused by small mammals which destroy about half the cocoons during a period of outbreak (9). The percentage thus destroyed is greatest under conditions of high diapause and following a high density of population.

Some idea of the total mortality in the cocoon can be gained from the fact that samples from beneath dead trees in central Gaspé showed that during the period of outbreak 82% failed to produce adults. Samples taken in 1943 on two plots in central New Brunswick, where there is less diapause, showed percentages of 62 and 68.

The Adult. There is little evidence of important control in the adult stage. Most adults apparently succeed in laying their full complement of eggs. This has remained fairly constant at around 45 per female, except when reduced by poor feeding conditions in the preceding larval stage. Some adults are destroyed by birds but in the typical spruce forest this number does not seem to be large. Climatic conditions are favourable except for a few which emerge too late in the season to complete oviposition.

The destructiveness of the sawfly up to 1938 may therefore be attributed to the fact that it had been introduced to a region where its food was plentiful over vast areas, where the climate was favourable and the biotic factors of control were insufficient to prevent an increase of population until the factor of food shortage was added. The latter appeared to be the only truly density-dependent factor of importance.

By 1938, however, several species of introduced parasites had become well established and began to exert considerable additional control in many parts of the infested area (2, 4). At the same time the first evidence was obtained that disease was affecting the sawfly, in the more southerly parts of its range. In 1939 both disease and parasites increased in effectiveness but the disease began to compete successfully with the parasites and became the chief factor in bringing about a general reduction of the outbreak (2, 9). If the disease disappears, the introduced parasites may again become important in maintaining control.

Mortality Caused by Disease

Some indications of the considerable amount of mortality caused by the disease have been given in the literature (2, 6). Dowden (8) described the large number of dead larvae in heavily infested areas in New Hampshire and Vermont in 1939 and noted that disease was also prevalent in light infestations. Dirks (7) reported in 1942 that on plots in Maine, 97% of the larvae which dropped were dead and that samples beaten from trees in August showed from 63 to 98% disease.

Exact measurement of the percentage of a generation which is killed is difficult, however. It has been attempted in different ways.

1. By beating the larvae from low-growing trees on to a 7 × 9 ft. sheet, with a 10-ft. pole. This gives an estimate only of the population and its condition at the time of sampling. It gives no information on the number of larvae which fell before sampling, and once the larvae have been disturbed it is impossible to tell how many of the healthy larvae would have become infected before maturity. Also, many diseased larvae adhere to the foliage and are not removed by beating.

2. By rearing known numbers of larvae from the egg on isolated branches over cotton mats. This involves only small numbers under conditions not typical of the forest. It provides information on the seasonal progress of the disease and the degree to which the various instars are affected.

3. By recording daily throughout the season the stage and condition of the larvae dropping from the trees on 2 X 2 ft. trays, as mentioned above. The trays were placed under trees distributed alternately among those used for cocoon samples. This method gives definite information on the number surviving to the sixth stage but the number of diseased larvae recorded is considerably less than the total because the majority of diseased larvae adhere to the foliage.

If these limitations are recognized, data of some value can be obtained. The third method is the only one which is of much use for estimating percentages of mortality in the stand. In Tables 1 and 2 are shown the results on two plots in central New Brunswick where daily records were

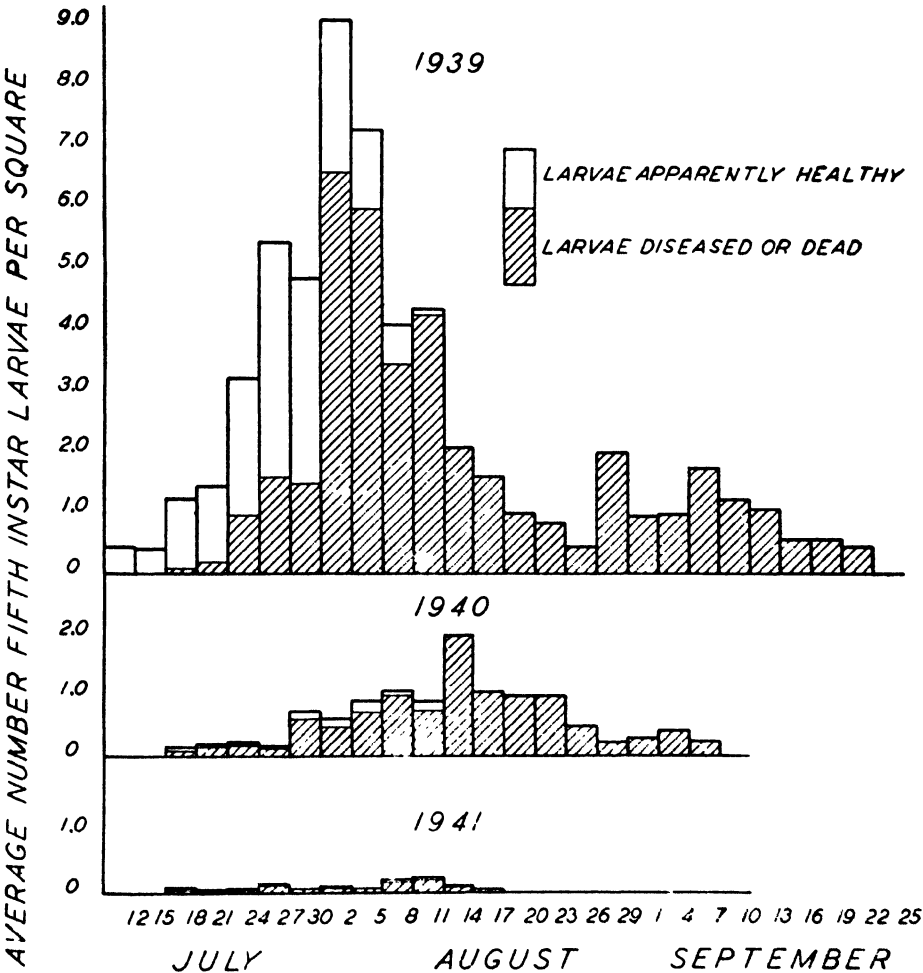


FIGURE 1. Drop of fifth stage larvae on Plot 1, 1939-41, shown as apparently healthy diseased.

possible from 1938 to 1941⁴. The trays all had cotton bottoms except those used at Young's Brook in 1938 and 1939. These had wire screens through which some of the young larvae escaped. The sides were treated with tanglefoot and so constructed as to prevent escape.

In Figure 1 is shown the drop of fifth stage larvae by 3-day periods on Plot 1 for 1939-41. This indicates the increasing effectiveness of the disease as the summer progresses. Only the earlier larvae of the first generation had any chance of survival. It also gives a good idea of the degree of mortality and the reduction in population each year.

TABLE 1.—LARVAL DROP AT YOUNG'S BROOK (PLOT 1) ON 44 TRAYS, 2 × 2 FT.

Stage	1938			1939			1940			1941		
	No. of larvae	Per-centage dis-eased	Per-centage of total dis-eased	No. of larvae	Per-centage dis-eased	Per-centage of total dis-eased	No. of larvae	Per-centage dis-eased	Per-centage of total dis-eased	No. of larvae	Per-centage dis-eased	Per-centage of total dis-eased
I	—	%	%	6	33.3	0.07	58	98.2	2.8	1	100	0.5
II	—	—	—	153	43.8	2.4	402	96.8	19.5	18	87.5	11.4
III	—	—	—	801	43.4	12.4	601	97.9	25.7	45	88.9	21.7
IV	—	—	—	409	51.8	7.6	408	96.5	19.8	51	90.2	25.5
V	1088	4.7	—	3118	70.2	78.8	607	91.4	27.9	87	88.8	40.7
VI	1389	—	—	465	12.7	2.1	19	26.3	0.2	2	50.0	0.5
Total all stages				4952	58.1	—	2095	94.2	—	210	86.2	—
Mortality if all dropped				—	91.8	—	—	99.3	—	—	99.5	—
Mortality if half dropped				—	94.8	—	—	99.7	—	—	99.7	—

TABLE 2.—LARVAL DROP AT ACADIA STATION (PLOT 3) ON 50 TRAYS, 2 × 2 FT.

Stage	1938			1939			1940			1941		
	No. of larvae	Per-centage dis-eased	Per-centage of total dis-eased	No. of larvae	Per-centage dis-eased	Per-centage of total dis-eased	No. of larvae	Per-centage dis-eased	Per-centage of total dis-eased	No. of larvae	Per-centage dis-eased	Per-centage of total dis-eased
I	1	%	%	8	87.5	1.1	4	100	1.5	0	%	%
II	8	0	0	17	70.5	2.0	11	100	4.3	1	100	1.4
III	23	4.3	0.5	91	77.0	11.8	23	95.7	8.5	4	25.5	1.4
IV	41	31.7	6.9	104	61.8	10.9	44	90.1	15.5	10	30.0	4.1
V	301	54.8	88.2	712	59.1	71.0	208	95.1	77.0	90	74.4	93.0
VI	590	1.3	4.2	397	4.5	3.0	23	8.7	0.7	11	0	—
Total	964	19.4	—	1329	56.5	—	333	88.6	—	116	65.5	—
Mortality if all dropped		39.7	—	—	71.5	—	—	93.4	—	—	90.5	—
Mortality if half diseased dropped		49.4	—	—	81.8	—	—	96.5	—	—	94.3	—

⁴ These plots were established by W. A. Reeks and M. L. Prebble and we are indebted to them and R. F. Morris for supplying most of the original data.

The annual reduction in larval population is best indicated by the number of larvae reaching the sixth stage in a healthy condition. This is a non-feeding stage which does not become diseased unless it was infected in the previous stage. It remains on the tree for one, or two days, then drops to the ground to spin the cocoon.

On Plot 1, for instance, where the infestation was heavy in 1936 and 1937, the total dropping as sixth stage in 1938 was 1,389. The number in each of the following three years was 465, 19, and 2. On Plot 3, where the infestation had been only moderate, the number of sixth stage dropping in the years 1938 to 1941 was 590, 397, 23, and 11. The reduction was greater and more rapid on the heavily infested plot.

The degree of larval mortality is best calculated by comparing the number of healthy sixth stage larvae with the total of all stages. For instance, in 1939 on Plot 1, 4,952 larvae dropped, of which 406 were healthy sixth. If it were assumed that all the larvae dropped, the percentage mortality would be 91.8. Similar calculations for 1940 give a mortality of 99.3%. This method, however, gives an underestimate since the majority of diseased larvae die on the trees and remain there for some time. Gradually, rain, wind and snow dislodge them, but generally not until after the recording of drop has ceased. Laboratory experiments and calculations from frass-drop measurements by Morris (10) suggest that about 80% remain on the foliage. It will be conservative to assume that half the diseased larvae do not drop in time to be recorded. If this is done the total number of larvae in the case of Plot 1 in 1939 was 4,952 plus 58.1%, or 7,829. The percentage mortality would then be 94.8. The corresponding figure for the next two years is 99.7.

This method of calculating the larval mortality in a stand is the most accurate one at present available⁵, but, in addition to the uncertainty regarding the number adhering to the foliage the following possible sources of error must be recognized: (1) If all sizes of larvae are not very carefully collected at least once a day the total larvae, and hence the percentage mortality, will be under-estimated; (2) Stages 1 to 5 which are recorded as healthy would often have become diseased before reaching the sixth stage; (3) Some of the healthy immature stages may regain the foliage and be recorded twice. Under the conditions on this laboratory's plots these errors are thought to be small, but to tend toward underestimation of mortality.

Mortality from Disease Compared with Total Mortality

The extent to which this larval mortality was reflected in the overwintering population of cocoons is indicated in Table 3. Figures are given for a plot near Dunbar Creek (Plot 2) as well as for the plots at Young's Brook (Plot 1) and Acadia Station (Plot 3). All are within 25 miles of each other. They represent three degrees of infestation.

It will be seen that in all cases the first decrease in cocoon population occurred following the season of 1939, when the disease was first recognized as an important control factor and larval mortality on two of the plots was estimated at 82 and 95%. Disease was present in 1938 and killed a good

⁵ Measurement of frass-drop appears to provide a more satisfactory method, as shown recently by Morris (10).

many larvae in the latter part of the summer. Data on larval drop for Plot 3 indicate a mortality that year of 50%. They are incomplete for Plot 1, but the number of sixth stage was about three times as great as in 1939 and the mortality was evidently insufficient to prevent an increase in cocoon population on all plots. The most striking reductions occurred following the seasons of 1940 and 1941, when the percentage larval mortality was not less than 99.7% on Plot 1 and 96.5 and 94.3% on Plot 3.

Although the estimated percentages of mortality due to disease are high, and there is an obviously close relation between the amount of disease and the reduction in the outbreak, it is not sufficient to quote such figures without considering what effect they would have on population trend and what relation they have to the total mortality. The importance of a percentage mortality figure depends on sex ratio and number of eggs laid per female, as well as the habits of the insect and the methods by which data are obtained.

The problem of determining the exact rôle of any single factor of control is difficult and often baffling. The difficulty lies in obtaining reliable data on all the interacting factors involved. In the present case an attempt to do so would seem to be justified since the mortality from disease was sufficiently high to make the other factors relatively unimportant. Thus errors due to the use of approximate estimations based on inadequate data are less serious. The attempt is made, however, not so much to present exact estimates of mortality as to indicate some aspects of the problem which must be considered, no matter how much it is simplified. Percentages are shown to the first decimal point regardless of the significance of the data, to demonstrate the importance of fractional changes in such percentages as they approach 100. The results only serve to emphasize the great care necessary in obtaining data on percentages of mortality and the importance of relating them to the habits and reproductive rate of the insect.

In comparing the estimated mortality from disease with the total mortality from all factors as shown by the cocoon counts it is necessary to consider the habit of diapause and the two overlapping generations per year.

TABLE 3.—COCOON POPULATION ON THREE PLOTS IN NEW BRUNSWICK*

(200 sq. ft. per plot).

	1937	1938	1939	1940	1941	1942	1943
1. Young's Brook (heavy)	31.8	66.7	95.8	28.6	1.1	0	0.04
2. Dunbar (medium heavy)	4.0	37.2	55.6	26.8	0.9	0.04	0.12
3. Acadia Station (medium)	—	9.2	21.0	5.5	0.09	0.24	0.20

* Average Number of Sound Cocoons in Spring Per 4 sq. ft.

In this district in 1939 and 1940 approximately 30% of the cocoons collected in the spring and observed under natural conditions remained in diapause. Studies of mortality in the cocoon stage indicate that in an average year almost 80% of these dormant cocoons would be destroyed by small mammals and other causes. The great majority of the remainder would emerge the following year. Thus spring counts would contain about $\frac{30 \times 20}{100}$ or 6% of the cocoons counted the previous spring, which had

remained in diapause and escaped destruction, in addition to those formed the previous summer. This hold-over of dormant cocoons prevents the effect of larval mortality from being fully reflected in the cocoon population of the following spring. For this reason 100% larval mortality would not wipe out a population unless repeated for at least two successive years. In the Gaspé, where diapause tendency is much stronger, high larval mortality reduces the cocoon population more gradually than in New Brunswick and more southerly areas (2, 12).

Of the cocoons formed by the first generation, a variable percentage produces adults for a second generation the same year. In central New Brunswick during 1937 and 1938 the authors estimate this at approximately 25%. Data are lacking for the following years but it would certainly be higher and probably close to 50%. This is because there is greater emergence from early than late cocoons, and when the disease is prevalent only the earlier larvae succeed in reaching the cocoon stage (Figure 1).

The overlapping of the two generations makes it impossible to study them separately under natural conditions with any degree of accuracy. It is difficult, however, to present a true picture of natural control unless some attempt is made to calculate the mortality in terms of each generation.

Before the disease appeared there was no evidence that there was any consistent difference in the amount of mortality suffered by the two generations outside the cocoon. It is assumed, therefore, that it was approximately equal in each generation. On the other hand, after the disease became prevalent, from 1939 to 1941, the mortality suffered by the second generation was 100%. This can be seen from Figure 1, for no healthy larvae dropped after the middle of August and second-generation larvae do not reach the fifth stage until after that time. The authors have therefore assumed 100% mortality in the second generation during these years.

In Table 4 are shown the following which have been calculated from the cocoon counts in Table 3.

1. *Index of Population Trend.* This is the number of sound cocoons in the spring expressed as a percentage of the number of sound cocoons in the previous spring.

TABLE 4.—INDEX OF POPULATION TREND (I) AND TOTAL MORTALITY PER GENERATION (M_1 AND M_2) CALCULATED FROM TABLE 3

			1937-8	1938-9	1939-40	1940-1	1941-2	1942-3
Plot 1.	Index population trend (I)		210	144	30	4	0?	200?
Young's Brook	Total	$M_1 = M_2 =$	95.0	96.3	98.6	100?	100?	—
	Percentage Mortality	$M_2 = 100, M_1 =$	—	—	98.5	100?	100?	—
Plot 2.	Index population trend (I)		903	140	48	34	4	300?
Dunbar	Total	$M_1 = M_2 =$	86.9	96.2	97.6	98.4	100?	—
	Percentage Mortality	$M_2 = 100, M_1 =$	—	—	97.3	98.2	100?	—
Plot 3.	Index population trend (I)		—	228	26	16	27	80?
Acadia	Total	$M_1 = M_2 =$	—	94.7	98.8	99.4	98.8	—
	Percentage Mortality	$M_2 = 100, M_1 =$	—	—	98.7	99.4	98.7	—

2. *Total Mortality per Generation.* This is the total percentage of a generation killed by all factors up to the time of the following spring. It does not include mortality to overwintering cocoons remaining in diapause during the year. It is necessarily based on sex ratio, number of eggs laid per female, and percentages of diapause.

Since males are rare (less than 1 in 1000), the sex ratio, or percentage of females divided by 100, is taken as 1.

The number of eggs which a female is capable of laying varies somewhat with the conditions of feeding of the larva from which she developed, and other environmental and inherent factors. It is therefore necessary to estimate this from an average of the number laid by a sample of females under natural conditions but protected from external causes of mortality. This has been found to remain fairly constant over a period of years and to approximate 45.

If I = index of population trend, or

$$\frac{\text{cocoons per sq. ft. present year}}{\text{cocoons per sq. ft. previous year}} \times 100,$$

M_1 (or M_2) = total percentage mortality of first (or second) generation,

E_1 = percentage emergence of adults from overwintering cocoons,

E_2 = percentage emergence from cocoons of first generation,

R = average number of eggs per female,

D = percentage of overwintering cocoons surviving in diapause,

then $I = 100 E_1 R (1-M_1) (1-E_2) + 100 E_1 R (1-M_1) E_2 R (1-M_2) + 100 D$.

$$\text{If } E_1 = \frac{70}{100}, R = 45, D = \frac{6}{100},$$

then $I = 3150 (1-M_1) (1-E_2) + 141750 E_2 (1-M_1) (1-M_2) + 6$.

Prior to 1939 it is assumed that $M_1 = M_2 = M$, and $E_2 = \frac{25}{100}$. Then

$$I = 2362.5 (1-M) + 35437.5 (1-M)^2 + 6,$$

which solves to

$$M = 1 - \frac{\sqrt{I + 33.31} - 6.27}{188.25}$$

If, during the years 1939-41, $M_2 = \frac{100}{100}$ and $E_2 = \frac{50}{100}$, then

$$I - 6 = 1575 (1-M_1),$$

$$\text{or } M_1 = 1 - \frac{1 - 6}{1575}$$

In considering the control effect of the various values for M it is helpful to know the total mortality in each generation which would be necessary to maintain a level population (i.e. $I = 100$). Assuming it to be equal for both generations, a mortality of 97.2% would be necessary. If the mortality of the second generation were 100%, the mortality of the

first would have to be 94.23%. If there were no diapause, a uniform mortality of $\frac{44}{45}$ or 97.8% would be needed in each generation to maintain a static population. This is Bremer's "normal coefficient of destruction" for one generation as quoted by Uvarov (15).

The percentages of larval mortality from disease in Tables 1 and 2 are in all cases less than the total mortality in Table 4. For instance, on Plot 1 in 1939 larval mortality was 94.8%, total mortality 98.6%; in 1940 the respective percentages were 99.7 and 100. The percentages approximated more closely as the disease became more effective. These differences are of course to be expected, since the other factors of control continued to operate after the appearance of the disease.

Adult and egg mortality probably remained much the same but many factors controlling the larval and cocoon stages were directly affected by the lowered density of the host population. Scarcity of foliage, which had become a factor of some importance on Plot 1 by 1937, although not on the other plots, ceased to have any effect after 1939. The percentages killed by introduced parasites at first increased as the population declined, and then decreased. There is some evidence that the percentages destroyed by *Podisus* sp. and small mammals may have behaved similarly (9). This seems to be indicated by those cases in Table 4 where *I* is less than 6. Occasionally there was overlapping as when infected larvae were attacked by *Podisus* or *Ixenterus* spp.

In spite of uncertainty regarding the exact control value of other factors since 1939, the figures for these plots indicate fairly clearly the importance of the disease in bringing about the end of the outbreak. They serve to confirm the conclusions drawn from less intensive sampling methods used throughout the infested area. During 1939-41 it was undoubtedly the major control factor and capable of reducing the sawfly numbers regardless of other factors. This was clearly the case on Plot 1 in 1940 and 1941, when larval mortality was conservatively estimated at 99.7%. Had there been no mortality in the adult or egg stage the percentage killed by disease probably would have been greater owing to higher density of larval population, and the total mortality much the same.

Prior to the appearance of disease, other factors were causing mortality of from 85 to 95% or more. The parasites, which were increasing rapidly, may have been capable of bringing the "average" generation mortality above the necessary 97% before scarcity of foliage and dying of trees added the factor of starvation. The disease, however, accomplished this before the potential value of the parasites could be determined and it destroyed so large a proportion of the population that other factors became of minor importance. It has continued as the dominant factor in the control complex at least up to 1942, but will probably not remain so after the population has been reduced to a certain level. Although the values shown for *I* in 1942-43 are not significant, they suggest that this level may have already been reached.

NATURE OF DISEASE

Laboratory experiments were limited at first by inability to rear larvae free from disease. Larvae were collected from disease-free areas in Ontario and shipped to Fredericton in sterilized boxes. They were reared by an

assistant isolated from the regular laboratory in another building. Foliage was used from shade-trees separated from the forest. Experiments were carried out within a few days with fair controls, but the precautions taken were insufficient to prevent eventual infection.

The difficulty was finally overcome by rearing larvae singly in special containers which could be sterilized by heat and used like a bacterial culture tube. By careful observance of the usual precautions in bacteriological work it has been found possible to rear disease-free lots continuously, even in the same incubator with infected lots.

External Symptoms

By infecting a number of larvae and examining them at 12-hour intervals, the process of infection has been followed up to death. The period from infection to appearance of first external symptoms varies with the temperature at which the larvae are reared. At 70° F. it is about 96 hours, with death occurring 2 or 3 days later. The period of infection to death at a mean temperature of 66° F. has been found to be 6 days and at 51° F., 11 days.

The first external symptom of infection among third, fourth and fifth stage larvae is a faint yellow discoloration of the third to fifth abdominal segments. In the case of first and second stage larvae there is a similar whitish discoloration but, owing to the small size of the early instars the first symptoms are not easily detected and in many instances are not observed. As the infectious process continues, the discoloured area becomes more pronounced and soon the larva loses its healthy green colour, changing first to yellow-green and after death to dark brown or black. Infected larvae cease to feed and become inactive. There is also a shortening of the body, not unlike that of larvae which have been starved. Diseased larvae often exude a dark brown fluid from the anus which cements the cadaver to the needle on which it has been feeding. The yellow-green protective fluid which is emitted from the mouth of healthy larvae when disturbed becomes milky-white in colour when the larvae are suffering from disease.

After death the larva is frequently completely flaccid and it is difficult to remove it from the foliage without rupturing the integument and liberating the liquid contents. There is no offensive odour. The cadavers may fall to the ground or remain attached to the foliage in a feeding position or suspended from the foliage by either extremity.

Internal Symptoms

If a smear of the body fluids of diseased larvae is examined with a high power dry or immersion lens it will be found to contain, besides the elements of disorganized tissues, myriads of polyhedral bodies. The average polyhedron measures 1.3 microns in diameter, ranging from 0.5 to 1.8 microns. Their shape varies as much as their size, but in general the form is that of a polyhedron with more or less rounded corners. They never assume the shape of a perfect sphere. They are highly refractive and resistant to stains.

The pathological process is concerned with the digestive tract and usually results in the complete destruction of the mid-gut. The cells of the epithelium of the mesenteron become enlarged. The polyhedral bodies are formed within the enlarged nuclei, from which they eventually escape. These nuclei appear like small dark bubbles when examined microscopically in the fresh state with a low power lens.

The digestive epithelium of healthy larvae is translucent and the gut appears green in colour, due to the large amount of partially digested food material which it contains. The digestive epithelium of a diseased larva becomes opaque and milky-white in colour and the gut is devoid of food.

The transition from an apparently healthy gut to a diseased gut is extremely rapid and in most cases the gut is apparently healthy 12 hours before the advanced symptoms.

The Pathogen

The blood and tissues of large numbers of diseased larvae have been examined and a good many cultures have been made. In most cases no bacteria or other micro-organisms are present until after death. Occasionally bacteria have been found in living diseased larvae but these appear to be of a secondary nature and associated with unfavourable rearing conditions.

From the external and internal symptoms, the presence of polyhedral bodies, and the pathological processes the disease appears similar to the virus or "wilt" diseases of various lepidoptera (15).

Experiments with Berkefeld V and N candle filtrates, however, have shown that the pathogen has been removed during the process of filtration. Further attempts with different techniques must be made before filterability can be definitely determined.

Methods of Transmission

Infection occurs by way of the mouth and larvae are easily infected by allowing them to feed on foliage which has been smeared or sprayed with aqueous dilutions of the body fluids of diseased living or dead larvae.

The apparently almost simultaneous appearance of the disease over large areas in both heavy and light infestations and the degree of control obtained within a short period of two or three years give some idea of the extreme-contagiousness of the disease and its efficient means of spread. In carefully controlled laboratory experiments, however, when the air has been relatively still, healthy larvae have only become infected after direct contact with diseased larvae or surfaces which have been contaminated by them. The spread of the disease through the air is dependent on the presence of water or dust particles which have been in contact with the pathogen and on air currents sufficient to carry them. It is improbable that spread by this means is sufficient alone to explain the rapid dissemination in nature. Experiments now in progress indicate that under certain conditions the pathogen may be carried into the cocoon without killing the insect and the emerging adult is contaminated. This may be an important means of overwintering and spread since the adults often fly long distances (4).

It is uncertain whether the pathogen overwinters on the foliage. Most of the cadavers are washed off before spring, and snow and rain are probably important cleansing agents. One experiment has shown that contaminated foliage lost its infectiveness during one month of sub-zero weather. The disease does not appear in the field until about the middle of July and this shows that the foliage is not heavily contaminated in the spring. On the other hand, the pathogen has survived in cadavers stored at just below freezing point for 13 months and in aqueous dilutions at room temperature for at least three months.

Resistance of Different Stages

The evidence all indicates that the disease originates in the alimentary tract and can only infect the five feeding larval stages. The sixth stage, eonymph, pronymph, pupa, and adult have remained uninfected even after immersion in water extract of diseased larvae.

The gut is normally evacuated by the sixth stage before the cocoon is spun (12). It has been found that if the period between the infection of a fifth stage larva and the evacuation of the gut is less than the period of incubation, normal development to the adult stage can take place. Although the adult is not affected, it can transmit the disease to some of its offspring, as already mentioned. It has not yet been determined whether the pathogen can be carried through the egg stage but the egg itself does not appear to be affected.

If, however, the time of infection of a fifth stage larva is such that lesions occur in the gut shortly before moulting, it may reach the sixth stage but be unable to evacuate the gut. A cocoon may be formed but death takes place in the eonymphal, or occasionally the pronymphal, stage. This explains how mortality from disease may sometimes occur within the cocoon. Such cases can generally be recognized by the dark flaccid appearance of the dead larva and the rather loosely spun cocoon.

The amount of this mortality is small when, as in 1940-42, the disease appears in quantity during the early stages of development. It is greatest when disease appears after most of the larvae are approaching maturity. During 1938 and 1939, eight collections made between Aug. 18 and Nov. 4, comprising some 6,000 cocoons, showed mortality of this kind ranging from 0.5 to 3.4%.

We have observed no cases of individual immunity or resistance in the feeding larval stages. All larvae fed contaminated foliage in experiments have died. Those which have survived the epidemic in the forest appear to have escaped infection by chance and in heavy infestations were confined to those which developed very early. The higher the density of the sawfly population, the lower has been the rate of survival. A thelytokous and relatively homozygous insect like the sawfly might be expected to show little variation in susceptibility. However, if the sawfly population in

North America has not previously been exposed to the disease, there can have been little time for potential resistance in the population to have developed through selection or other means of adaptation.

Epidemiology

Up to the present there is very little to suggest that the disease is greatly influenced by weather conditions. Density of sawfly population seems to be the most important factor determining its control effect. Although it has proved remarkably effective under conditions of light infestation, there is no doubt that the percentage of disease increases with the numbers of its host. This increase is independent of secondary effects of crowding, such as shortage of food.

There is probably a minimum level of population on which the disease can maintain itself, once all the adults have emerged from cocoons formed by infected larvae as described above. It is already becoming less prevalent at points in New Brunswick and may disappear from considerable areas to reappear only after new outbreaks of the insect develop.

The possibility of storing the pathogen in virulent form so that it can be re-established if necessary is being investigated. Preliminary experiments have shown that it can be introduced to new areas by spraying foliage with a water extract of diseased larvae.

ACKNOWLEDGMENTS

The authors wish to acknowledge considerable assistance rendered by Mr. D. J. MacLeod and Mr. J. L. Howatt of the Dominion Laboratory of Plant Pathology at Fredericton in the early stages of the work, particularly in connection with the preparation and testing of filtrates. Dr. C. E. Atwood, Dr. L. L. Daviault and Mr. K. E. Stewart of the Division of Entomology, Science Service, Dominion Department of Agriculture, have assisted generously in carrying out experiments on the establishment of the disease in new areas in Ontario and Quebec. Acknowledgment is extended to Dr. R. W. Glaser of the Rockefeller Institute for Medical Research for suggestions.

REFERENCES

1. BALCH, R. E., W. A. REEKS and S. G. SMITH. Separation of the European spruce sawfly in America from *Gilpinia polytoma* (Htg.) and evidence of its introduction. Can. Ent. 73 : 198-203. 1941.
2. BALCH, R. E. Annual reports on the European spruce sawfly outbreak. Ann. Rept. Dept. of Lands and Forests of Nova Scotia, Halifax, N.S. 1934 to 1942.
3. BALCH, R. E. The outbreak of the European spruce sawfly in Canada and some important features of its bionomics. Jour. Econ. Ent. 32 : 412-418.
4. BAIRD, A. B. A review of the spruce sawfly parasite situation. Woodlands Sec., Can. Pulp and Paper Assn. Index No. 549 (F-3). 1940.
5. DAVIAULT, L. L. La mouche a scie Europeenne de l'epinette dans la forets du nord du St-Laurent. La Foret Quebecoise 3 : 3-7. 1941.
6. DE GRUYSE, J. J. Brief note on the so-called mysterious disease of the spruce sawfly. For. Chron. 17 : 43-44. 1941.

7. DIRKS, C. O. Report of work and observations on the European spruce sawfly in Maine, 1942. Mimeo. Univ. of Maine. 1943.
8. DOWDEN, P. B. Larval disease prevalent in heavy infestations of the European spruce sawfly in southern New Hampshire and Vermont. Jour. of For. 38 : 970-972. 1940.
9. MORRIS, R. F. Preliminary notes on the natural control of the European spruce sawfly by small mammals. Can. Ent. 74 : 197-202. 1942.
10. MORRIS, R. F. The use of frass-drop measurement in forest insect investigations, with particular reference to the European spruce sawfly, *Gilpinia hercyniae* (Htg.). MS. Div. of Ent., Dept. of Agric., Ottawa, Can. 1944. To be published.
11. PEIRSON, H. B. Control work on the European spruce sawfly in 1940. 23rd Rept. of Forest Commissioner, Augusta, Maine. 1941.
12. PREBBLE, M. L. The diapause and related phenomena in *Gilpinia polytoma* (Htg.). Can. Jour. Res. D, 19 : 295-322; 323-346; 350-362; 417-436; 437-454. 1941.
13. PREBBLE, M. L. Sampling methods in population studies of the European spruce sawfly, *Gilpinia hercyniae* (Htg.), in Eastern Canada. Trans. Roy. Soc. Can. 37 : 93-126. 1943.
14. REEKS, W. A. Native insect parasites and predators attacking *Diprion polytomum* (Htg.) in Canada. 69th Ann. Rept. Ent. Soc. Ont. : 25-28. 1938.
15. RIVERS, T. M. Filterable viruses. Ch. 8, pt. 2. Williams and Wilkins Co., Baltimore, Md. 1928.
16. UVAROV, B. P. Insects and climate. Trans. Ent. Soc. of London 79, p. 137. 1931.

A REVIEW OF THE NORTH AMERICAN SPECIES OF THE GENUS *ARGYROTAENIA* STEPHENS, (LEPIDOPTERA, TORTRICIDAE)¹

T. N. FREEMAN

Science Service, Department of Agriculture, Ottawa, Ont.

[Received for publication August 21, 1944.]

This paper is presented in an endeavour to assist those engaged in the identification of the species of *Argyrotaenia* Steph. This genus is, at present, comprised of fifteen species which, as larvae, feed mainly on the foliage of coniferous and deciduous trees, and often occur abundantly enough to be of economic importance.

A study of the genitalia of both sexes showed that, because of the interspecific similarities, the characters found in these structures could not be relied upon for specific separation but appear to be quite usable for generic restriction. The segregation of the various species is, therefore, accomplished mainly by differences in wing pattern. These differences are tabulated to form an artificial key and are illustrated from photographs of specimens, or a series of specimens when it is desirable to indicate the variation of wing pattern within a species. In a few instances, illustrations of types and homotypes are included, thanks to the co-operation of the authorities at the Philadelphia Academy of Natural Sciences and at the American Museum of Natural History. The author's notes pertaining to these types have been incorporated in the text.

It is very difficult at the present time to obtain material or distributional data and, in consequence, the study has been based largely on specimens contained in the Canadian National Collection, and notes dealing with some of the more southern species are fragmentary. No attempt has been made to assemble a complete bibliography for each species, and only references to the taxonomic history are included. References to the vast economic literature, dealing with several of the species, may be readily obtained by consulting Colcord's indices of American economic entomology.

Argyrotaenia Stephens

Genotype: *Tortrix politana* Haworth

Stephens, 1852, List Spec. Anim. Brit. Mus., X (Lep.), 67.

Pierce and Metcalf, 1922, Gen. Tort. Lep. Br. Is., 1.

McDunnough, 1939, Check List Lep. Can. U.S.A. (Part 2), 57—*Argyrotaenia* Hbn. cited in error for *Argyrotaenia* Steph.

Cubitus of hind wing above without fringe of hair at base, but with a fringe on the base of the second anal; fore wing with radius 4 and 5 separate, the latter running to the apex or outer margin, medius 3 and cubitus 1 separate; hind wing with radius and medius approximate; fore wing smoothly scaled; palpi porrect, clavate or triangular; thorax with posterior crest; male antennae without notch at base.

¹ Contribution No. 2323, Division of Entomology, Science Service, Department of Agriculture, Ottawa.

Male genitalia: Claspers distinctly rounded; transtilla invaginated; cornuti broad, short, pointed and deciduous.


Female genitalia: Ductus bursa narrow, with a strong sclerotic thickening at the junction of the bursa.

Argyrotaenia is separated from *Eulia* Hbn. by the following characters:

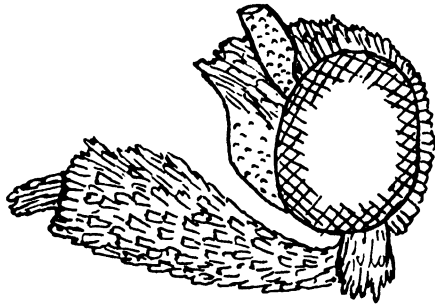
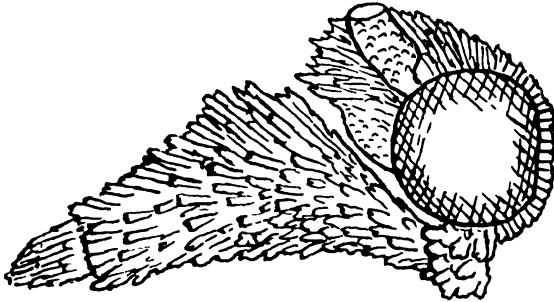
Argyrotaenia: Hind wing with radius and medius approximate; aedoeagus broad; bursa membraneous.

Eulia: Hind wing with radius and medius stalked; aedoeagus aciculate; bursa spiculate, somewhat resembling that of the geometrid genus *Eupithecia*.

KEY TO THE NORTH AMERICAN SPECIES OF *Argyrotaenia* STEPH.

1. Hind wings white, at least on costal half. 2
Hind wings smoky, brownish, or tawny. 6
2. Fore wing with a large central brown patch and with round, pure white or cream coloured patches surrounding the margin. **allsellana** (Rob.)
Fore wing obliquely crossed by one or more fasciae. 3
3. Fore wing with numerous, small, light brown spots and two narrow, parallel, brown fasciae. **quercifoliata** (Fitch)
Fore wing with single, broad, often suffused, median fasciae. 4
4. Fore wing with shining white area between the median band and the outer costal spot; fringe of hind wing without dark basal line. **coloradana** (Fern.)
Area between median band and outer costal spot not white but concolorous with the ground colour. 5
5. Second joint of labial palpi strongly tufted on upper side (fig. 2) and broadest at the middle, this giving it a triangular appearance. **citrana** (Fern.)
Second joint of labial palpi clavate, not tufted, widest at its apex (Fig. 1)
repertana n. sp.
6. Fore wings brown or orange, with two narrow parallel darker fasciae. 7
Fore wings more variegated, fasciae when present much broader. 8
7. Fore wings bright orange. **quadrifasciata** (Fern.)
Fore wings brown. **juglandana** (Fern.)
8. Fore wings rust coloured, with two or three very distinct silvery white costal-streaks
niscana (Kft.)
Fore wing without silvery white costal streaks, although complete whitish fasciae may be present. 9
9. Base of fore wing outstandingly ochereous to the inner edge of the median band, at least on costal half. 10
Base of fore wing may be somewhat ochereous but not standing out as a distinct ochereous basal patch. 11
10. Ochereous basal patch uniform over the whole basal area from costa to the dorsal margin. Rest of wing shining leaden-grey. Expanse ♂, 19 mm. Described from California. **gloverana** (Wlsh.)
Ochereous basal patch on costal half of fore wing only. Expanse 14-16.5 mm.
 a few males and all females of **velutinana** (Wlk.)
11. Fore wings reddish brown, irrorated with darker cross lines, or the bands of the wings with darker outer margins. **tabulana** n. sp.
Fore wings not irrorated with darker cross lines, or the bands not distinctly margined with darker shades. 12
12. Fore wings distinctly banded with reddish-brown, the outer margin of the basal patch extending from the dorsal margin to the costa. A pine feeder. **pinatubana** (Kft.)
Fore wings may have traces of reddish-brown banding but not distinctly so, and in such cases the outer margin of the basal patch does not extend to the costa. 13

13. Fore wing grey or greyish-white; basal patch usually obsolete; median fascia weak behind, very pronounced in costal region where it is more or less joined to outer costal spot to form a large elongate triangle which extends almost to apex of wing. Expanse 18–23 mm. **mariana** (Fern.)
 Fore wing may be greyish but not with large elongate costal triangle extending almost to apex of wing. 14
14. Outer edge of basal patch distinct from dorsal margin to costa; fore wing generally grey with complete whitish fascia and the median band uniformly coloured at least on its inner margin; a spruce feeder. **occultana** Frmn.
 Outer edge of basal patch obliterated on costal half. 15
15. Ground colour ochereous or greyish, with two blackish or dark brown spots, the inner one representing the costal portion of the median band, below which this band is reddish-brown. Banding not very distinct. Expanse 11.5–14 mm.
 ♂ **velutinana** (Wlk.)
 Ground colour dark brown with purplish-brown bands; hind wing light reddish. Described from Florida. **amatana** (Dyar)

FIGURE 1. Head of *reperana* n. sp.FIGURE 2. Head of *citrana* (Fern.)

***Argyrotaenia velutinana* (Walker)**

(Pl. I, Figs. 1–6)

- Cacoecia* ? *velutinana* Walker, 1863, Cat. Lep. Het., XXVIII, 313.
Cacoecia triferana Walker, 1863, Cat. Lep. Het., XXVIII, 314.
Tortrix lutosana Clemens, 1865, Proc. Ent. Soc. Phil., V, 138; Zeller 1876, Verh. z.-b. Ges. Wien, XXV, 225.
Tortrix incertana Clemens, 1865, Proc. Ent. Soc. Phil., V, 138; Robinson, 1868, Trans. Am. Ent. Soc., II, 278, Pl. VI, figs. 57, 58.
Tortrix velutinana (Walker), Grote and Robinson, 1868, Trans. Am. Ent. Soc., II, 83.
Lophoderus triferanus (Walker), Walsingham, 1879, Ill. Lep. Het., IV, 15, Pl. LXIII, fig. 9; Fernald, 1882, Trans. Am. Ent. Soc., X, 15.

Lophoderus velutinana (Walker), Fernald, 1882, Trans. Am. Ent. Soc., X, 16.

Eulia triferana (Walker), Dyar, 1902, List N.A. Lep., No. 5421.

Eulia velutinana (Walker), Dyar, 1902, List N. A. Lep., No. 5424; Forbes, 1923, Cornell Univ. Agri. Exp. Stat., Memoir 68, 490.

Argyrotaenia velutinana (Walker), McDunnough, 1939, Check List Lep. Can. and U.S.A. (Part 2), No. 7443.

Argyrotaenia lutosana (Clem.), McDunnough, 1939, Check List Lep. Can. and U.S.A. (Part 2), No. 7444.

Because of the sexual dimorphism of this species, Walker (1863) and Clemens (1865), working independently at about the same time, both described the male and female as distinct species. A few years later, Robinson (1868) misidentified Clemens' *lutosana* and figured as this an undescribed species to which I gave the name *ocullana* Frmn. In 1879, Walsingham recognized that all the names proposed by Walker and Clemens belonged to one species. Later authors have followed either Robinson or Walsingham but a recent examination of Clemens' types shows that his names are synonymous with one another and also with Walker's names, as judged from Walsingham's depiction of Walker's species.

In the Ottawa district there are two or possibly three generations a year with the largest number of individuals flying in late May or early June and again in July. The males of the spring generation are generally darker than those emerging later in the summer, this difference not being so apparent in the females. In general the male moth is ochereous or greyish-ochereous with a rather poorly defined basal patch, usually distinct on the dorsal half only and angled outward at the fold. The median band is distinct, blackish or very dark brown on the costal half, brownish-ochereous on the dorsal half, the two halves being sharply defined. Beyond this is the usual *Argyrotaenia* costal spot followed below, or prolonged into, a brownish-ochereous spot. In the female the basal patch is further reduced to a short black spur representing the outer margin of that patch; and the whole area within, above to the costa, and outward to the inner edge of the median band is ochereous and stands out against the uniformly reddish brown median band.

Expanse: ♂, 11.5–14 mm.; ♀, 14–16.5 mm.

Type locality: North America [*velutinana* (Wlk.), *triferana* (Wlk.)]; Virginia [*lutosana* (Clem.)]; unknown [*incertana* (Clem.)].

Type: British Museum [*velutinana* (Wlk.), *triferana* (Wlk.)]; Philadelphia Academy of Natural Sciences, [*lutosana* (Clem.), *incertana* (Clem.)].

Food plant: The larva feeds generally as a leaf-tyer on almost any plant apparently, except conifers, and has been recorded, possibly in error on balsam fir.

Distribution: Que., Ont., N.Y., Mass., Penna., Mo., Tex.

***Argyrotaenia repertana* n. sp.**

(Fig. 1; Pl. I, Figs. 7–12)

Head and thorax brownish-ochereous. Fore wing brownish-ochereous on a white ground, with darker median band and outer costal spot. Basal patch brownish-ochereous, its outer margin angled outwardly at the fold,

poorly defined throughout and extending to the costa. The area between the basal patch and the median band is concolorous with the basal patch on the costal half and becomes whitish on the dorsal half. In two of the paratypes this white area extends to the costa and in consequence the basal patch is outstanding. *Median band* oblique, reddish-brown, *containing a minute spot of white at the middle of its outer margin*. Outer costal spot concolorous with the median band, the space between brownish-ocherous. Terminal area from apex to tornus whitish. Fringe brownish-ocherous. *Hind wing white*, with slightly clouded anal area and light ocherous apex; fringe white with slightly darker basal line. Expanse of holotype, 16.5 mm. of paratypes, 15–19 mm. Moth in late May and June.

Holotype—♀, Waweig, N.B., June 15, 1938 (T. N. Freeman); No. 5408 in the Canadian National Collection, Ottawa, Ont.

Allotype—♂, St. Andrews, N.B., June 4, 1938 (T. N. Freeman).

Paratypes—1 ♂, 4 ♀, Waweig, N.B., June 10–16, 1938 (T. N. Freeman); 1 ♂, 1 ♀, St. Andrews, N.B., June 9 and 18 (respectively) 1938 (T. N. Freeman); 1 ♀, S. Milford, N.S., June 28, 1934 (J. McDunnough); 1 ♀, White Point Beach, Queens Co., N.S., emerged in office Jan. 27, 1936 (J. McDunnough), reared from *Aralia* sp.; 1 ♀, Barrington Passage, N.S., June 19, 1910 (C. H. Young); 5 ♂, Aweme, Man., May 27, 1922 (N. Criddle); 1 ♂, Aweme, Man., June 13, 1923 (N. Criddle); 1 ♂, Saskatoon, Sask., May 31, 1924 (K. King); 2 ♂, Passadumkeag, Me., June 18, 1938 and June 2, 1935 (A. E. Brower); 3 ♂, Augusta, Me., May 30, 1940 (A. E. Brower); 1 ♂, Augusta, Me., May 17, 1941 (A. E. Brower). Paratypes in the U. S. N. M. and the collection of Dr. A. E. Brower, Augusta, Me.

This species resembles, somewhat, the females of *velutinana* (Wlk.) and might be confused with it. However it is readily separated by its larger size and mostly white hind wings.

Food plant: *Aralia* sp.

Distribution: N.S., N.B., Que., Man., Sask., Me.

***Argyrotaenia pinatubana* (Kearfott)**

(Pl. I, Figs. 13–18)

Tortrix politana Haworth, Packard, 1890, Fifth Report U.S. Ent. Comm., 91 (life history). *Eulia pinatubana* Kearfott, 1905, Can. Ent., XXXVII, 9; Forbes, 1923, Cornell Univ. Agri. Exp. Stat., Memoir 68, 490.

Argyrotaenia pinatubana (Kearfott), 1939, McDunnough, Check List Lep. Can. and U.S.A. (Part 2), No. 7445.

Sexes similar. Head and thorax ocherous. Abdomen grey, blackish or mouse coloured with ocherous apical tufting more noticeable on the male. Fore wing with broad well defined orange to reddish-ocherous basal patch, the outer margin of which is distinct from costa to posterior margin; median band and outer costal spot well defined and concolorous with the basal patch, the median band usually with a lighter area near the middle of its inner margin; the bands are separated by a complete fascia of whitish or light ocherous which colour predominates in the apical region. Hind wing smoky, becoming paler basally; fringe paler with darker basal line. Expanse: ♂, 13–15 mm.; ♀, 14–18 mm.

Somewhat resembles *reperiana* Frmn. and the females of *velutinana* (Wlk.) but is more distinctly banded. Moth from late April to early June.

Type locality: Essex Co. Park, N.J.

Type: American Museum of Natural History.

Food Plant: the larvae feeds on Pine, binding the needles together to form a tube in which it lives. It is often injurious.

Distribution: N.S., N.B., Que., Ont., Maine, N.J., N.Y.

Remarks: The illustrated homotype was ably compared with Kearfott's type by Dr. C. V. Mitchener of the American Museum of Natural History.

***Argyrotaenia occultana* Freeman**

(Pl. I, Figs. 19-24)

Tortrix lutosana (Clemens), Robinson, 1868, Trans. Am. Ent. Soc., II, 279, Pl. VI, fig. 59. *Argyrotaenia occultana* Freeman, 1942, Can. Ent., LXXIV, 57; 1942, Brown and McGuffin, Can. Ent., LXXIV, 60 (larva).

This is the species misidentified by Robinson and figured by him as *lutosana* (Clem.). Sexes similar. A moderate sized species with dark brown basal patch, median fascia, and outer costal spot; the spaces between these areas appearing as greyish or white fascia; *outer margin of the basal patch distinct from the costa to the hind margin*. In general colour it could only be confused with the much larger *mariana* (Fern.), the separating characters being noted in the key and accompanying plate. Expanse: 17-19 mm. Moth in late June and early July.

Type locality: Mt. Lyall, Que.

Type: In the Canadian National Collection, Ottawa, Ont.

Food Plant: Spruce.

Distribution: N.S., N.B., Que., Ont., Alta., N.Y.

***Argyrotaenia mariana* (Fernald)**

(Pl. I, Figs. 43-45)

Lophoderus mariana Fernald, 1882, Trans. Am. Ent. Soc., X, 67.

Eulia mariana (Fernald), 1902, in Dyar List N. A. Lep., No. 5427; Forbes, 1923, Cornell Univ. Agri. Exp. Stat. Memoir 68, 491.

Argyrotaenia mariana (Fernald), McDunnough, 1939, Check List Lep. Can. U.S.A. (Part 2), No. 7450.

Sexes similar. Head white, rarely grey. Thorax white or light ochreous with brown posterior crest. Abdomen whitish or grey with lighter apical tuft. Fore wing white with ochreous, brown, or black markings; basal patch mostly indistinct and indicated by a dark ochreous patch with angled black outer margin, which usually extends only to the middle of the wing and is most prominent at the hind margin; median band black, rarely brown on costal half where it often connects with the black, rarely brown outer costal spot in varying degrees of completion, below the middle the band is suddenly light brown, often indistinct along the outer margin; a light grey or light brown spot is usually present just

above the tornus; rest of the wing white, finely striated with light ochereous and with short black striae along the hind and outer margins. Fringe light ochereous. Hind wing smoky; fringe white with dark basal line. Expanse: 17–24 mm. Moth in May or June.

Type locality: Described from four males from Orono, Me., Mass., and N.Y.

Cotypes: 4♂ in the United States National Museum.

Food plants: Apple, blueberry, and possibly oak.

Distribution: N.S. to Ont., south to Fla.

Remarks: A large whitish species, with the median band and outer costal spot black, and often united to form a large black costal triangle beyond the middle. It is often a pest in apple orchards.

***Argyrotaenia tabulana* n. sp.**

(Pl. I, Figs. 25–30)

Sexes similar. Head, palpi, and thorax, light brown. Fore wing light brownish-grey with a pinkish cast and irrorated with dark reddish-brown lines which represent the outer borders of the usual *Argyrotaenia* pattern. The basal patch is represented by two dark reddish-brown angulated lines. The oblique median band is a bit darker than the ground colour, shows a purplish cast, and is bordered outwardly and inwardly with irregular reddish-brown distinct lines. The costal spot beyond the median band is reddish-brown with darker inner and outer edges, and is contiguous or slightly remote from a similarly coloured elongate spot above the tornus. Beyond the costal spot are one or two short dark reddish-brown preapical lines from the costa; fringe light reddish-brown. Hind wing smoky, becoming lighter toward the base; fringe light with dark basal line and becoming tawny toward the apex. Underside of fore wing smoky with light ochereous costal and outer margins, and obliquely crossed with evenly spaced dark fuscous lines. Underside of hind wings white with several dark fuscous spots at the apex. Expanse of holotype, 17.5 mm., of paratypes, 13–17 mm.

This species exhibits a certain amount of variation of maculation. The ground colour varies from light brown to greyish and the median band may be represented only by the darker outer borders, or it may be considerably darker than the ground colour but with still darker distinct outer borders. The maculation of this species somewhat resembles that of *pinatubana* Kft. Moth from late April to early June.

Holotype—♀, Constance Bay, Ont., Apr. 29, 1941 (J. McDunnough); No. 5409 in the Canadian National Collection, Ottawa.

Allotype—♂, Kazubazua, Que., June 7, 1927 (F. P. Ide).

Paratypes—3 ♂, Biscotasing, Ont., June 6, 11, 1931 (Karl Schedl); 2 ♀, Kazubazua, Que., June 11, 1935 (G. S. Walley); 1 ♀, Hawk Lake, Ont. Reared on Jack Pine by the Forest Insect Survey and emerged in incubator Jan. 29, 1941; 2 ♂, 2 ♀, Peachland, B.C., May 23, 1936 (A. N. Gartrell); 1 ♀, Jesmond, B.C., bred from *Pinus contorta* and emerged

in laboratory Feb. 16, 1936 (J. K. Jacob); 1 ♀, Baynes Lake, B.C., reared on *Pinus ponderosa* Dougl. and emerged in incubator Feb. 9, 1942. Paratypes in the U.S.N.M.

Food plant: Pine.

Distribution: Que., Ont., Man., B.C.

Remarks: Mines Jack Pine needles, webbing two needles together and eating out the inside of one needle very thoroughly causing the needle to appear cream coloured and making it very conspicuous.

***Argyrotaenia citrana* (Fernald)**

(Fig. 2; Pl. I, Figs. 31-36)

Tortrix citrana Fernald, 1889, Ent. Amer., V, 18.

Argyrotaenia (Tortrix) citrana (Fernald), Basinger, 1935, Cal. Agr. Mo. Bull., XXIV, 233.
Tortrix citrana Fernald, McDunnough, 1939, Check List Lep. Can. U.S.A. (Part 2), 57, No. 7414.

A variable species with acute apex of fore wing. Ground colour of fore wing grey, reddish-brown or ochreous; basal patch darker than ground colour or absent; oblique median band blackish or dark brown, narrower on costal third and fading out on its outer edge posteriorly; outer costal spot distinct or absent. Fringe light to dark ochreous. Hind wing white with a few short, dark, striae, more noticeable on outer half; fringe whitish, sometimes with darker basal line. Labial palpi with second joint tufted on upper side (fig. 2) and broadest at the middle giving it a triangular lateral aspect. Expanse: ♂, ♀, 14-19 mm. Moth intermittently throughout the year.

Type locality: California.

Type: A ♀ in the United States National Museum.

Food plants: Orange and other citrus fruits, Solidago, willow, Geranium, rose and Asparagus. Apparently a general feeder.

Distribution: Calif., north in greenhouses to B.C.

Remarks: A pest of considerable economic importance to the citrus fruits of California, and in greenhouses in British Columbia. It is the only species studied in the genus which possesses a triangular second palpal joint.

***Argyrotaenia niscana* (Kearfott)**

(Pl. I, Figs. 37-38)

Eulia niscana Kearfott, 1907, Trans. Amer. Ent. Soc., XXXIX, 94.

Eulia camerata Meyrick, 1912, Ent. Mon. Mag., XLVIII, 35.

Argyrotaenia niscana (Kearfott), McDunnough, 1939, Check List Lep. Can. U.S.A. (Part 2), No. 7449.

Sexes similar. Head and thorax rust coloured. Abdomen grey-brown. Fore wing rust coloured with narrow, white fasciae and streaks; basal patch rust coloured, wide, its oblique outer margin slightly irregular and well defined from costa to hind margin; beyond the basal patch is a narrow silvery-white complete fascia, often outlined in part with black; beyond, the

wing is rust coloured with a short silvery-white costal streak just beyond the middle, its posterior end curved abruptly outward and broken to include a round black dot, or continued to the tornus; near the apex of the costa, is a short white streak, and still nearer the apex is a light ochereous streak (sometimes broken) extending almost to the light ochereous tornal region; fringe light ochereous or tawny, darker at the apex. Hind wing entirely dark smoky, slightly striated with a darker shade; fringe lighter with dark basal line. Expanse: 15 to 18 mm. Moth from May to July.

Type locality: Carmel, Calif.

Type: ♂ in the American Museum of Natural History.

Food plant: Unknown.

Distribution: Calif.

Remarks: Easily distinguished by its rust-red colour and outstanding silvery-white costal streaks.

Argyrotaenia coloradana (Fernald)

(Pl. I, Fig. 39)

Lophoderus coloradana Fernald, 1882, Trans. Am. Ent. Soc., X, 67.

Eulia coloradana (Fernald), 1903, in Dyar List N. A. Lep., 485, No. 5425.

Argyrotaenia coloradana (Fernald), McDunnough, 1939, Check List Lep. Can. U.S.A. (Part 2), No. 7447.

Sexes apparently similar. Head and abdomen light ochereous. Thorax reddish-brown. Fore wing with broad, well defined, reddish-ochereous basal patch, the outer margin of the latter distinct from the costa to the posterior margin of the wing; median band distinctly reddish-brown, darker on the costa, becoming lighter behind, its inner margin narrowly but distinctly outlined with yellow, and deeply indented just below the radial vein; outer costal spot large, deep reddish-brown, contrasting with the white costal area on either side; between the bands and in the apical region of the wing the white ground colour is obscured by streaks and patches of light ochereous; fringe light ochereous with white rays. Hind wing white, with smoky anal region which may easily be erased in spreading, or in poor specimens; fringe white. Expanse: 21–26 mm. Moth in July.

Type locality: Colorado.

Cotypes: 1 ♂, 1 ♀, in the United States National Museum.

Food plant: Unknown.

Distribution: Colo., Utah.

Remarks: Easily recognized by the distinct reddish-brown outer costal spot which contrasts with the white ground surrounding it. Somewhat resembles *Archips argyrospila* Wlk. but the latter has the hind wings entirely smoky.

***Argyrotaenia quadrifasciana* (Fernald)**

(Pl. I, Figs. 40-42)

Lophoderus quadrifasciana Fernald, 1882, Trans. Am. Ent. Soc., X, 67.*Eulia quadrifasciana* (Fernald), 1902, Fernald in Dyar List N. A. Lep., No. 5419; Forbes, 1923, Cornell Univ. Agri. Exp. Stat., Memoir 68, 491.*Argyrotaenia quadrifasciana* (Fernald), McDunnough, 1939, Check List Lep. Can. U.S.A. (Part 2), No. 7453.

Sexes dimorphic. *Male*: Head, thorax and fore wing yellow, the latter uniformly reticulate with orange and crossed by an antimedial and post-medial narrow, complete, purplish-brown (rarely orange) fascia; apical region suffused with purplish-brown; fringe light ochereous, dark in tornal region. Hind wing dark fuscous; fringe light fuscous with darker basal line. *Female*: Like the male except the bands are orange (rarely purplish), apical region of fore wing reticulated with orange and hind wings brownish-orange. Fringes as in male. Expanse: ♂, 15-18 mm.; ♀, 17-19 mm. Moth in June and July.

Type localities: Me., N.H., Mass., N.Y., Ill.*Cotypes*: 2 ♂, 1 ♀, in the United States National Museum.*Food plants*: *Crataegus*, *Amelanchier*.*Distribution*: P.E.I. to Ont., south to Penn. and Mo.*Remarks*: Easily distinguished by its orange-yellow colour with orange or purplish-brown bands.***Argyrotaenia quercifolia* (Fitch)**

(Pl. I, Figs. 46-49)

Argyrolepis quercifolia Fitch, 1858, Trans. N.Y. State Agr. Soc., XVIII, 826. (Reprinted 1859, Fifth Rept. Noxious Insects N.Y., 46).*Tortrix* (*Argyrotoxa*) *trifurculana* (Zeller), 1875, Verh. Zool.-bot. Ges. Wien, XXV, 226.*Tortrix quercifolia* (Fitch), Fernald, 1902, in Dyar List N. A. Lep., No. 5399.*Eulia quercifolia* (Fitch), Forbes, 1923, Cornell Univ. Agri. Exp. Stat., Memoir 68, 491.*Argyrotaenia quercifolia* (Fitch), McDunnough, 1939, Check List Lep. Can. U.S.A. (Part 2), No. 7452.

Sexes similar. Creamy-yellow, finely dotted with light brown; two narrow, darker brown, oblique fascia, the post median one forked at the costa, and connected near its middle to a curved, subterminal, dark brown fascia, also forked on the costa just before the apex; fringe white or yellowish with darker basal line. Hind wing and fringe pure shining white. Expanse: ♂, 16-20, mm., ♀, 19-24 mm. Moth in June and July.

Type locality: New York?*Type*: A ♂ without abdomen in the United States National Museum.*Food plants*: Oak, buckthorn and witch-hazel.*Distribution*: Que. to Man. south to Tex. and Fla.

Remarks: Some specimens (fig. 46) possess a light brown blotch near the middle of the fore wing and thus resemble *alisellana* (Rob.). However, the numerous light brown dashes in the basal and terminal areas of *quercifoliana* readily distinguish this species. Individuals rarely occur which are almost entirely light cream coloured, the brown maculation being obliterated.

Argyrotaenia juglandana (Fernald)

(Pl. I, Figs. 50-53)

Tortrix (*Lophoderus*) *juglandana* Fernald, 1879, Can. Ent., XI, 155.

Eulia juglandana (Fernald), Fernald, 1902, in Dyar List N.A. Lep., No. 5420; Forbes, 1923, Cornell Univ. Agri. Exp. Stat., Memoir 68, 491.

Argyrotaenia juglandana (Fernald), McDunnough, 1939, Check List Lep. Can. U.S.A. (Part 2), No. 7454.

Sexes quite similar. **Male:** Fore wing brown, inclined to be speckled and crossed by two narrow, dark brown, oblique fascia which are wider on the costa. Fringe dark brown to blackish, becoming light toward the apex. Hind wing and fringe, shining fuscous. Female darker brown than the male with no speckled appearance. Expanse: ♂, 17-19 mm., ♀, 21-26 mm. Moth in June and July.

Type locality: Described from 11 males and 15 females from the following localities: Mass., N.Y., Ont., Ohio, Wis. Part of the type series was reared from Hickory by J. Angus of West Farms, N.Y.

Cotypes: 3 ♂, 3 ♀, in the United States National Museum.

Food Plant: Hickory, also recorded on *Viburnum*.

Remarks: This is the largest species in the genus. Full grown larvae occur in a longitudinally rolled hickory leaf in the latter half of June and pupate beneath the bark along the trunk of the tree.

Distribution: Que. to Ont. south to Penna. and Minn.

Argyrotaenia amatana (Dyar)

(Pl. I, Fig. 54)

Lophoderus amatana Dyar, 1901, Jour. N.Y. Ent. Soc., IX, 24.

Eulia amatana (Dyar), Fernald, 1902, in Dyar List N.A. Lep., 485, No. 5422.

Argyrotaenia amatana (Dyar), McDunnough, 1939, Check List Lep. Can. U.S.A. (Part 2), 58, No. 7446.

Head and thorax reddish-brown. Fore wing brownish-orange with purple-brown basal patch, median band and outer costal spot, the first not reaching the costa; terminal space whitish. Hind wing orange, fading basally and of the same colour as that of the hind wing of the female of *quadrifasciana* Fern.

This species is easily recognized by the orange brown colour of both fore and hind wings and in size approaches *velutinana* Wlk. Expanse: ♂, 13 mm., ♀, 18-19 mm.

Type locality: Palm Beach, Florida.

Type: United States National Museum.

Food plants: Recorded by Dyar, 1901, op. cit., as bred from *Annona glabra* Linn. = *laurifolia* Duval. and, *Nectandra coriacea* (Sw.) Griseb. = *Wildenoviana* Nees. Also avocado (U.S.N.M. record). According to Dyar the larvae ties up the leaves with a series of transverse walls of web, leaving a round hole in each web near the leaf for the larva to pass through.

Distribution: Florida.

The only specimen the author has of this species is a rather worn male from Perrime, Florida, June 8, 1923, G. F. Moznette Coll., reared from avocado and kindly loaned for study by the authorities of U.S.N.M. through Mr. Carl Heinrich.

***Argyrotaenia alisellana* (Robinson)**

(Pl. I, Figs. 55-56)

Tortrix alisellana Robinson, 1869, Trans. Am. Ent. Soc., II, 267, Pl. I, fig. 15.

Eulia alisellana (Robinson), Fernald, 1902, in Dyar List N. A. Lep., No. 5428; Holland, 1913, Moth Book, 423, Pl. XLVIII, fig. 39; Forbes, 1923, Cornell Univ. Agri. Exp. Stat., Memoir 68, 491.

Argyrotaenia alisellana (Robinson), McDunnough, 1939, Check List Lep. Can. and U.S.A. (Part 2), No. 7451.

Sexes similar. Head and thorax white. Fore wing light brown with white or cream coloured basal third, which sometimes contains a few light brown scales, and with marginal, pure white or cream coloured, rounded blotches as follows: One at the middle of the costa, one at the costal four-fifths, one at the middle of the outer margin, and one smaller one just before the tornus on the hind margin. Hind wing white. Fringes white. Expanse: 18-24 mm. Moth in June and July.

Type locality: Ohio.

Type: Probably lost.

Food plant: Unknown.

Distribution: Que., Ont., N.Y., Ohio, Penna., Ind., Ill., and Va.

***Argyrotaenia gloverana* (Walsingham)**

Lophoderus gloveranus Walsingham, 1879, Ill. Lep. Het. B.M., 14, Pl. LXIII, fig. 7.

Eulia gloverana (Walsingham), 1903, Fernald, in Dyar List N. A. Lep., 485, No. 5425.

Argyrotaenia gloverana (Walsingham), 1939, McDunnough, Check List Lep. Can. U.S.A. (Part 2), No. 7448.

Very little appears to be known about this Californian insect and it is absent from most collections. The author has never seen it, his key characters being based entirely upon the original description and figure, the former of which reads as follows: "Head whitish grey, thickly clothed above and in front; palpi whitish grey, brownish at the sides, projecting the length of the head beyond it: antennae slightly pubescent: thorax

with a raised ferruginous tuft of scales at the back; patagia of the same colour. Fore wings—with the costa arched; apical margin very oblique, slightly emarginate below the apex—rather shining leaden grey, with a ferruginous patch at the base extending over one fourth of the wing, externally margined with brownish fuscous; an irregular, waved, greyish-fuscous fascia about the middle, clearly defined only on its inner edge; beyond and before it are some transverse streaks and lines of brownish fuscous, especially towards the apex; the apical portion of the costa clothed with brownish fuscous, and some streaks of the same colour running through the grey cilia. Hind wings pale brownish fuscous; cilia paler, 1♂. Expanse of wings 19 millims."

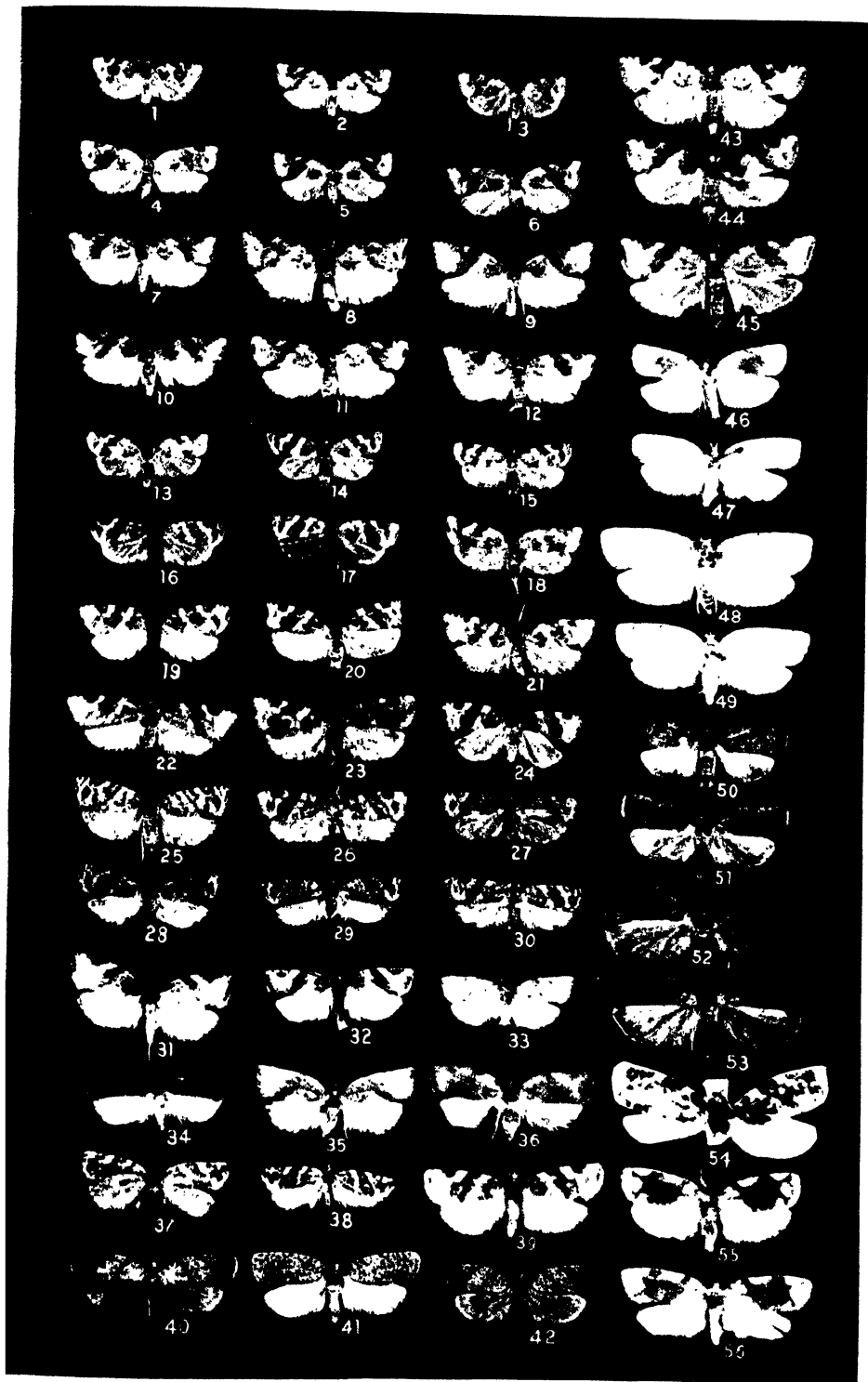
"Near Mount Shasta, California, Sept. 3rd, 1871."

Type: British Museum.

Food plant: Unknown.

EXPLANATION OF PLATE I (*See opposite page*)

1. *A. velutinana* (Wlk.), ♂, Constance Bay, Ont., (agrees with ♂ type *lutosana* Clem.).
2. *A. velutinana* (Wlk.), ♂, Mer Bleue, Ont.
3. *A. velutinana* (Wlk.), ♂, Ottawa, Ont.
4. *A. velutinana* (Wlk.), ♀, Meach Lake, Que.
- 5, 6. *A. velutinana* (Wlk.), ♀'s, Ottawa, Ont.
7. *A. repertana* n. sp., ♀, holotype, Waweig, N.B.
8. *A. repertana* n. sp., ♂, paratype, Augusta, Maine.
9. *A. repertana* n. sp., ♂, paratype, Aweme, Man.
10. *A. repertana* n. sp., ♂, allotype, St. Andrews, N.B.
11. *A. repertana* n. sp., ♀, paratype, White Pt. Beach, N.S.
12. *A. repertana* n. sp., ♀, paratype, Barrington Passage, N.S.
13. *A. pinatubana* (Kft.), ♂, Chelsea, Que., homotype (Mitchener, 1943).
14. *A. pinatubana* (Kft.), ♂, Wright, Que.
15. *A. pinatubana* (Kft.) ♂, Chelsea, Que.
16. *A. pinatubana* (Kft.), ♀, S. Milford, N.S.
17. *A. pinatubana* (Kft.), ♀, Tabusintac, N.B.
18. *A. pinatubana* (Kft.), ♀, Ottawa, Ont.
19. *A. occultana* Frmn., ♂, holotype, Mt. Lyall, Que.
20. *A. occultana* Frmn., ♂, Mt. Laurier, Que.
21. *A. occultana* Frmn., ♂, paratype, Mer Bleue, Ont.
22. *A. occultana* Frmn., ♀, allotype, Mt. Lyall, Que.
23. *A. occultana* Frmn., ♀, paratype, Burbidge, Que.
24. *A. occultana* Frmn., ♀, paratype, McAdam, N.B.
25. *A. tabulana* n. sp., ♀, holotype, Constance Bay, Ont.
- 26,27. *A. tabulana* n. sp., ♂♂, paratypes, Biscotasing, Ont.
28. *A. tabulana* n. sp., ♂, allotype, Kazabuzua, Que.
- 29,30. *A. tabulana* n. sp., ♀♀, paratypes, Peachland, B.C.
31. *A. citrana* (Fern.), ♂, Riverside, Calif.
- 32,33. *A. citrana* (Fern.), ♂♂, Victoria, B.C.
- 34,36. *A. citrana* (Fern.), ♀♀, Ladysmith, B.C.
35. *A. citrana* (Fern.), ♀, Victoria, B.C.
- 37,38. *A. niscana* (Kft.), ♀♀, Cajon Valley, Calif.
39. *A. coloradana* (Fern.), ♂, Estes Park, Colo.
40. *A. quadrifasciana* (Fern.), ♂, Norway Bay, Que.
41. *A. quadrifasciana* (Fern.), ♀, Meach Lake, Que.
42. *A. quadrifasciana* (Fern.), ♂, Bobcaygeon, Ont.
43. *A. mariana* (Fern.), ♂, Ottawa, Ont.
44. *A. mariana* (Fern.), ♂, Berwick, N.S.
45. *A. mariana* (Fern.), ♀, Annapolis Royal, N.S.
46. *A. quercifoliana* (Fitch), ♂, Aweme, Man.
47. *A. quercifoliana* (Fitch), ♀, Simcoe, Ont.
48. *A. quercifoliana* (Fitch), ♀, Meach Lake, Que.
49. *A. quercifoliana* (Fitch), ♀, Ottawa, Ont.
- 50-53. *A. juglandana* (Fern), ♂♂, ♀♀, Simcoe, Ont.
54. *A. amatana* (Dyar), ♀, Perrine, Fla. (From Photo)
- 55,56. *A. alisellana* (Rob.), ♂♂, Mt. Lake, Va.



(Photo by Marier)

BOOK REVIEW

A SOURCE BOOK OF AGRICULTURAL CHEMISTRY by Charles A. Browne, Bureau of Agricultural and Industrial Chemistry, U.S. Department of Agriculture; 250 pages, cost \$5.00. Published by Chronica Botanica Co., Waltham, Mass., U.S.A.; Canadian Agents, Wm. Dawson Subscription Service Ltd., Toronto, 2, Ont.

The author devoted upwards of forty-five years to the field of Agricultural Chemistry where his duties consisted of teaching and research for industrial organizations, educational institutions and the U.S.D.A. About two decades of this time was spent as chief chemist and supervisor of agricultural research for the Bureau of Chemistry and Soils, from which he retired in 1940. As a result of long years of experience, he is eminently qualified to write a book on Agricultural Chemistry. The following statement in the preface gives Dr. Browne's reason for the book and his treatment of the subject matter: "The purpose of the author in writing the present work has been to give a more accurate and complete account, than has hitherto appeared, of the origins of agricultural chemistry and of the relationships of Liebig's work to that of his predecessors. In doing this he has preferred so far as possible to let these predecessors in selected passages give their own accounts of the work selected for description, with no attempts at modernization of language. This volume is therefore primarily a source-book and while there can be a just difference of opinion in the choice of selective material, it is hoped that the various quotations and translations submitted will give the reader a good general perspective of developments in the history of agricultural chemistry from early beginnings down to the time of Liebig. Unless otherwise stated the various translations of original source material were made by the author."

The book consists of an introduction in which the author defines Agricultural Chemistry. This is followed by seven chapters beginning with Agricultural Chemistry in ancient times (early Greek period 1400 B.C. — 79 A.D., Thales to Pliny) and tracing this development through the early Royal Society period (Boyle to Tull); through the period of the alchemists; the early and late Phlogiston periods; the period from Lavoisier to DeCandolle and on to include Liebig.

The book is well indexed both as to subjects and authors. It is by no means a text book on, nor is it a complete history of the development of Agricultural Chemistry. However, it is an excellent reference for both student and instructor interested in the part chemistry has played in the scientific explanation and development of agriculture. Dr. Browne has brought together under the covers of this book many of the important original investigations and the theories which have influenced our present conceptions regarding the importance of proper food and protection for both the plant and animal kingdoms. He has presented the theories of the various authors referred to and some of their controversies without any conscious attempt on his part to influence the reader.

Many of the original papers and books reviewed by the author are available only in the larger and better equipped libraries, and not a few of us welcome the opportunity of placing copies of *A Source Book of Agricultural Chemistry* in our libraries and on our reference shelves

F. A. WYATT.

HISTORY, DESCRIPTION, DISTRIBUTION AND PERFORMANCE OF AJAX AND EXETER OATS¹

J. N. WELSH²

Dominion Laboratory of Cereal Breeding, Winnipeg, Man.

[Received for publication September 15, 1944]

INTRODUCTION

Previous to 1935, the varieties of oats grown in Canada were susceptible to many diseases such as stem rust, crown rust, loose and covered smut, and halo-blight. The only exceptions were Anthony and Green Russian, two varieties originating in the United States, which were resistant to certain races of stem rust, and grown to a limited extent in Manitoba.

In 1935, the Ontario Agricultural College, Guelph, released Erban, a variety that is resistant to both smuts and moderately resistant to certain races of crown rust in the mature plant stage. It is grown extensively in Eastern Canada, particularly in areas where crown rust is usually prevalent. In 1936, the Dominion Laboratory of Cereal Breeding, Winnipeg, distributed Vanguard which is resistant to the races of stem rust that commonly occur in Canada. It is widely grown in Manitoba and to a considerable extent in Saskatchewan and Alberta, as well as in certain areas of Ontario and Quebec that are subject to damage from stem rust. Both Erban and Vanguard are medium early maturing varieties. As earlier maturing varieties are more suitable in some areas and later maturing ones in others, there is a need of disease resistant varieties with these characteristics. To meet this need, two new varieties, Ajax and Exeter, were distributed by the Dominion Laboratory of Cereal Breeding, Winnipeg. The purpose of the present paper is to give the history, description and performance of these two varieties.

HISTORY

Ajax, R.L. 1114, C. A. N. 660, came from a cross made in 1930 at the Dominion Laboratory of Cereal Breeding, Winnipeg, between Victory and the stem rust resistant variety Hajira. Continuous plant selection was practised with this cross until 1936, at which time the plants had reached the sixth generation. Numerous lines were increased in 1937 and the most promising of these were given a yield test at Winnipeg in 1938. R.L. 1114 (Ajax) was the most outstanding and was placed in the Co-operative Rod Row Tests in 1939. It performed exceptionally well, both in 1939 and in 1940, and on the basis of these tests was accepted for registration in 1941.

Exeter, R.L. 53, C. A. N. 661, came from a cross made in 1929 at the Dominion Laboratory of Cereal Breeding, between Victory and Rusořa. The latter parent is one of the Green Russian selections made and named at the North Dakota Experiment Station and is resistant to the common races of stem rust. Each stem rust resistant line of this cross was bulked separately in the F₃ and given a yield test for three years. Selections were then made from the highest yielding ones and a number of them were

¹ Contribution, number 131, from the Cereal Division, Experimental Farms Service, Department of Agriculture, Ottawa, Canada.

² Paper read before the Western Canadian Society of Agronomy at Saskatoon, Sask., June 22 and 23, 1944.

³ Senior Assistant Agricultural Scientist.

placed in a rod row test at Winnipeg in 1937. A few of the most promising lines were placed in the Co-operative Rod Row Tests in 1938 and R.L. 53 (Exeter) which was one of the highest yielding lines in these tests was accepted for registration in 1941.

DESCRIPTION

Ajax

This variety has a spreading type of panicle with the branches more acute than in many other varieties. (Figure 1.) It is comparatively short and compact and when viewed from certain angles in the field appears to be



FIGURE 1. Panicle of Ajax oats

partially unilateral, due to the fact that the uppermost spikelets tend to form in a cluster. The kernels are white and medium in size with the awns fairly numerous. The number of veins on the glumes range from 7 to 11, 9 being the predominating number. The nodes are glabrous and according to Ridgway's Colour Standard³ the under side of the leaves are classified as Varley Green and the upper side as Deep Dull Yellow Green. It is an early maturing variety, a week to ten days earlier than Victory, and has good length and strength of straw. Because of its strength it is a suitable variety for sowing on summerfallow, but under conditions of rank growth some lodging is to be expected. To offset this, heavier rates of seeding, $2\frac{1}{2}$ to 3 bushels per acre, are recommended for summerfallow. In disease reaction it is resistant to the common races of stem rust, being similar to

³ Ridgway, Robert. Colour standards and colour nomenclature. 43 pp. Hoen & Co., Baltimore. 1912.

Vanguard and Exeter in this respect, but differs from these varieties in that it is more susceptible to the less prevalent ones. It is moderately resistant to crown rust in the mature stage, and has quite a high degree of resistance to loose and covered smut, and to halo-blight.

Exeter

This variety has a spreading type of panicle somewhat similar to Victory. (Figure 2.) It has fewer awns than Ajax and the number of veins in the glumes range from 9 to 11, with the greater majority of them having 9 veins. The kernels are white and although they are not quite as large as



FIGURE 2. Panicle of Exeter oats

those of Victory, they resemble that variety in shape and plumpness. The nodes are glabrous and the colour of the leaves is identical with that of Ajax. It is a medium late maturing variety, being approximately two days earlier and two inches shorter in the straw than Victory. Exeter is similar to Victory in strength of straw, but since it is not considered to be a strong-strawed variety it will not stand up on fallow as well as stronger varieties such as Ajax. In general, it is recommended for those areas where stem rust is likely to occur and where the later maturing varieties are better adapted. It is resistant to the common races of stem rust and has considerable resistance to halo-blight, but is susceptible to other diseases.

DISTRIBUTION OF SEED

The method used in distributing seed of Ajax to farmers was to supply members of the Canadian Seed Growers' Association with Foundation Stock and to retain control of the produce by means of contracts. Orders

were taken for the seed and passed on to the growers most conveniently situated to make deliveries. Foundation Stock was distributed to seed growers in the winter of 1941-42 and a general distribution of 15,824 bushels was made in the winter of 1942-43. The classification of this amount into seed grades and amounts distributed in each province is given in Table 1.

During the season of 1943 it was estimated that between 500,000 and 600,000 bushels of Ajax oats were produced in Western Canada. The indications are that the greater portion of this was used for seed in 1944. As a consequence the variety is very rapidly becoming of major importance in the oat production of Western Canada.

Foundation Stock of Exeter oats was supplied to seed growers in the winter of 1941-42 in small quantities. This stock which was handled by three seed growers was increased to 3,500 bushels by the end of the 1943 season and was distributed to farmers following the same plan as with Ajax. Table 2 gives details of the distribution.

TABLE 1.—NUMBER OF BUSHELS OF REGISTERED, CERTIFIED, AND COMMERCIAL SEED OF AJAX DISTRIBUTED THROUGHOUT SIX PROVINCES DURING THE WINTER OF 1942-43

Grade	Provinces						Total
	Quebec	Ontario	Manitoba	Saskatchewan	Alberta	British Columbia	
Registered	3	125	5618	4480	471	12	10,709
Certified	—	87	2121	1971*	729	12	4,920
Commercial	—	—	87	108	—	—	195
Total	3	212	7826	6559	1200	24	15,824

* 1110 bushels were distributed by the Swift Current Experimental Station.

TABLE 2.—NUMBER OF BUSHELS OF REGISTERED CERTIFIED AND COMMERCIAL SEED OF EXETER DISTRIBUTED THROUGHOUT FOUR PROVINCES DURING THE WINTER OF 1943-1944

Grade	Provinces				Total
	Ontario	Manitoba	Saskatchewan	Alberta	
Registered	12	1329	1032	36	2409
Certified	—	381	168	—	549
Commercial	—	314	219	18	551
Total	12	2024	1419	54	3509

AGRONOMIC DATA

The agronomic data are discussed under two main headings: Controlled Plot Experiments, in which Ajax and Exeter are compared with other varieties in tests throughout Canada, and Performance of Ajax Under Farm Conditions, which summarizes the results obtained from questionnaires sent out to all farmers receiving seed of Ajax in 1943.

Controlled Plot Experiments

These data were obtained from the annual reports, sent to the Cereal Division, Central Experimental Farm, Ottawa, by all the Experimental Farms and Stations in Canada and from annual reports at the Dominion Laboratory of Cereal Breeding, Winnipeg, for periods ranging from one to four years, as well as from reports on co-operative tests conducted by the Ontario Agricultural College, Guelph, in western Ontario at 33 testing points in 1942 and 28 in 1943. The data are given in Tables 3 and 4.

Table 3 summarizes the general plant characteristics of Ajax and Exeter and certain other varieties. Since conditions vary in the different parts of Canada the data were classified separately for the Maritime Provinces, Ontario and Quebec, the Prairie Provinces, and British Columbia.

Ajax matures approximately 10 days earlier than Victory in the Maritime Provinces and British Columbia and about 7 days earlier in other parts of Canada. It shows good length and strength of straw in all areas, and is comparatively high in bushel weight except in the Maritime Provinces where it is considerably lower than Exeter or Victory, but equal to Erban. It is lower in hull content in the Prairie Provinces than in Ontario and Quebec, but the data for the former are for more than one year at a number of stations, whereas those for the latter are for one year at Lennoxville. In disease reaction it is resistant to the common races of stem rust, moderately resistant to crown rust, and has a fairly high degree of resistance to both smuts, and to halo-blight.

Exeter is 2 to 3 days earlier maturing than Victory in most areas and although the data for British Columbia indicate that Exeter is a week earlier than Victory, the difference between the two varieties is the same at Agassiz as in other parts of Canada, whereas at Saanichton, it is 12 days earlier than Victory over a 3-year period. Exeter has a slightly shorter straw than Victory and except in the Prairie Provinces it appears to be shorter than Ajax. It is quite similar to Victory in strength of straw, but slightly lower than that variety in bushel weight and weight per one thousand kernels. It is resistant to the common races of stem rust and moderately resistant to halo-blight, but is susceptible to crown rust, and although it is classed as a smut susceptible variety, it is less susceptible than Vanguard.

Table 4 gives the yields of Ajax and Exeter in comparison with other varieties in tests conducted by the Dominion Experimental Farms and Stations in Eastern and Western Canada and in co-operative tests conducted by the Ontario Agricultural College in western Ontario for periods ranging from one to four years.

In Eastern Canada Ajax yielded well in comparison with other varieties at all stations with the exception of Charlottetown and L'Assomption, while at Ste. Anne de la Pocatiere, Roxton was higher yielding than Ajax on clay land but lower yielding on sandy land over a 3-year period. Exeter, although it was not tested at all stations, yielded well in the Maritime Provinces and at Lennoxville.

In Western Canada Ajax yielded particularly well at Winnipeg, Morden, Brandon, and Scott, and although it produced lower yields than some of the later maturing varieties at all of the other stations, it yielded

well in comparison with other early maturing varieties. Although Exeter was lower yielding than Ajax at the three stations in Manitoba, it was higher yielding than the other varieties in the tests. In Saskatchewan it was the highest yielding variety at three stations and yielded equally as well as Ajax at Scott, while in Alberta it was the highest yielding variety on the average for two years at Lacombe and yielded comparatively well at the other three stations. In British Columbia it produced high yields at Agassiz and Prince George, but it does not appear to be suited to the conditions at Saanichton where the earlier maturing varieties appear to be better adapted.

Performance of Ajax Under Farm Conditions

Questionnaires were sent out to all those receiving seed of Ajax in 1943. One thousand and fifty were returned, 490 from Manitoba, 425 from Saskatchewan, 114 from Alberta, 21 from western Ontario, and 2 from Armstrong in British Columbia. The information received was summarized by provinces with each of the three prairie provinces being roughly divided into northern, central, and southern zones. The data for the prairie provinces and western Ontario are given in Table 5 and are discussed under the following headings: Suitability for Area, Strength of Straw, Yield, Time of Maturity, Stem Rust Reaction, Shattering, Feed Value of Straw, and Suggested Improvements.

The information received from British Columbia is not included in Table 5 as the number of growers reporting is too few. However, one grower considered Ajax suitable, but preferred a larger kernel and the other thought that owing to its earliness it would be desirable under certain conditions.

Adaptability—Ajax appears to be a widely adaptable variety as in all areas of each province the greater percentage of the growers considered it to be satisfactory for their district. A number, however, were undecided and a few considered it unsuitable, due mainly to its small kernel and in some instances on account of low yield and weakness of straw.

Strength of Straw—In all provinces the greater percentage of growers observed Ajax to have a stronger straw than that of the other variety grown on the farm, although a number found it to be equal in strength, and a few weaker. In all areas of Manitoba, Vanguard was the variety most commonly grown, along with some Victory, Banner, Anthony, Green Russian, and Gopher. In northern Saskatchewan, Victory appears to be the predominating variety, with some Banner, Anthony, Legacy, Vanguard, Eagle, Gopher, and Valor. In the central and southern areas, Vanguard as well as some of the other above mentioned varieties, is grown to a considerable extent. In Alberta the varieties commonly grown in all areas appear to be Victory, Banner, Eagle, and Legacy, while in Ontario, although only a few gave the name of the variety commonly grown, Vanguard was the only variety mentioned.

Yield—In the majority of cases, those sending in questionnaires gave the yield of Ajax as well as that of the main crop. They were not always comparable, however, as in the majority of cases Ajax was grown on breaking or fallow and the main crop on second crop land, under which

conditions it would naturally yield comparatively well. Furthermore, as it was sown in lots of only 3, 6, or 9 bushels, the acreage was small. However, the greater majority of the farmers considered the yield to be satisfactory with only a few finding it to be low yielding.

Thirty-eight farmers stated that Ajax was grown under the same conditions as the main crop, 10 in Manitoba, 34 in Saskatchewan, and 4 in Alberta and although the numbers are small the results are considered to be of interest as well as indicative. Fifteen farmers in Ontario gave the yields obtained with Ajax as well as that of the main crop and although it is not known if they were grown under the same conditions, the results were also thought to be of interest.

On the 10 farms in Manitoba in which Ajax was grown under the same conditions as the main crop, it yielded considerably higher than other varieties. On 5 of the farms they were sown on fallow and on the other 5 farms on second crop land. In the northern and southern parts of Saskatchewan Ajax gave higher yields than the other varieties on the average for all farms, and was only lower yielding on 1 farm in each area. In the central area, however, there was little difference between the average yield of Ajax and that of the other varieties, although on 5 of the 8 farms it gave higher yields. The yields for Alberta are for only 4 farms, but on 3 of them Ajax yielded considerably higher than the other varieties, while on the fourth farm, at Innisfail, it yielded the same as Legacy. Of the 21 growers reporting from Ontario, which included farms in the Rainy River District to as far east as Bowmanville, all but 3, who were undecided, were satisfied with the yield of Ajax.

In all provinces there were districts in which the growing season was unfavourable. In some the season was late due to spring rains and in others it was quite dry. Ajax apparently did well, for the most part, when sown late, and in the drier areas the majority thought it had more drought resistance than other varieties.

Maturity—From the information received it is apparent that most farmers desire an early maturing oat variety, as the earliness of Ajax was favourably commented upon by a great many growers. Early maturing varieties can be harvested in many areas before the wheat harvesting commences and in areas subject to fall frosts they are more likely to escape frost damage than the later maturing ones, while in all areas, especially in Western Canada, they are useful as a cleaning crop.

Stem Rust—Stem rust caused considerable damage to the older susceptible varieties in 1943 and in spite of the new race of rust that appeared in considerable proportions for the first time, only 11 farmers observed Ajax to be heavily rusted and in these cases the variety was either sown quite late or rusted in low spots in the field; Vanguard and Anthony were reported to be heavily rusted under similar conditions. Quite a number, however, found light to medium infections of rust on Ajax, while a considerable number observed no rust.

Shattering—As Ajax is a new variety little is known concerning its value as a combine oat; 27 farmers, however, stated that it did not shatter easily, while 9 thought it had a tendency to shatter.

Feed Value of Straw—Eleven farmers commented upon the feed value of Ajax straw; 5 considered it either made good sheaf feed or that the stock liked the straw, while 6 thought the straw to be too coarse.

Suggested Improvements—While a number of growers reported that the kernel of Ajax was heavy and plump, the majority expressed a preference for a larger kernel. Although the majority of the farmers considered Ajax to be superior or at least equal to other varieties in straw strength and yield, it also could be improved in these respects.

SUMMARY

Ajax is from a cross, made in 1930, between Victory and Hajira. It is resistant to the common races of stem rust, moderately resistant to crown rust in the mature plant stage, and has a fairly high degree of resistance to smut and halo-blight. It is an early maturing variety, with good strength of straw and a medium sized white kernel, and appears to be fairly widely adapted to conditions in both Eastern and Western Canada.

Exeter is from a cross, made in 1929, between Victory and Rusota. It is resistant to the common races of stem rust and has considerable resistance to halo-blight, but it is susceptible to other diseases. It is slightly shorter in the straw than Victory and 2 to 3 days earlier, except at Saanichton where over a 3-year period it was 12 days earlier. In Eastern Canada it yielded well in the Maritime Provinces and at Lennoxville, Quebec, while in Western Canada it is better suited to the central and northern regions, particularly in areas where stem rust is likely to occur.

ACKNOWLEDGMENTS

The writer is indebted to the cerealists of the Dominion Experimental Farm Service and to Dr. G. P. McRostie, Professor of Field Husbandry, Ontario Agricultural College, Guelph, for their agronomic data, and to the pathologists of the Dominion Laboratory of Plant Pathology, Winnipeg, for their data on disease reaction.

TABLE 3.—SUMMARY OF AGRONOMIC DATA AND DISEASE REACTIONS OF AJAX, EXETER, AND CERTAIN OTHER VARIETIES IN TESTS CONDUCTED BY THE DOMINION EXPERIMENTAL FARMS AND STATIONS FOR A PERIOD OF FROM ONE TO THREE YEARS IN MARITIME PROVINCES, ONTARIO AND QUEBEC, THE PRAIRIE PROVINCES, AND BRITISH COLUMBIA

Varieties	Maturity	Height	Str. of straw	Wt. per bus	Wt. per 1000 K	Hull	Stem rust infection	Crown rust infection	Smut infection	Halo-blight infection
	Days	inches	1-10	lb.	gm.	%	%	%	%	%
MARITIME PROVINCES										
Average of 3 years at Charlottetown and Fredericton, and 2 years at Nappan										
Ajax	93.6	42.3	9.7	35.9	28.2	—	Trace	17.0	—	—
Exeter	100.4	40.4	9.6	37.2	30.6	—	—	—	—	—
Victory	103.6	42.7	9.2	38.6	33.2	—	—	—	—	—
Vanguard	98.2	41.4	9.6	34.9	29.8	—	0.0	21.0	—	—
Erban	97.7	41.8	9.9	35.0	35.2	—	15.0	25.6	—	—
Roxton	104.6	46.2	9.2	36.4	34.8	—	—	—	—	—

TABLE 3.—SUMMARY OF AGRONOMIC DATA AND DISEASE REACTIONS OF AJAX, EXETER, AND CERTAIN OTHER VARIETIES IN TESTS CONDUCTED BY THE DOMINION EXPERIMENTAL FARMS AND STATIONS FOR A PERIOD OF FROM ONE TO THREE YEARS IN MARITIME PROVINCES, ONTARIO AND QUEBEC, THE PRAIRIE PROVINCES, AND BRITISH COLUMBIA—*concluded*

Varieties	Maturity	Height	Str. of straw	Wt. per bus.	Wt. per 1000 K	Hull	Stem rust infection	Crown rust infection	Smut infection	Halo-blight infection
	Days	inches	1-10	lb.	gm.	%	%	%	%	%
ONTARIO AND QUEBEC										
Average of 3 years at Ottawa and 1 year at Lennoxville										
Ajax	83.2	43.2	9.8	34.7	28.4	26.0	0.0	4.0	—	—
Exeter	89.0	39.9	8.9	34.4	29.2	—	0.0	20.0	—	—
Banner	91.9	43.6	7.9	34.4	31.5	26.1	34.2	30.0	—	—
Vanguard	87.0	40.7	9.0	34.4	30.5	24.3	0.0	13.5	—	—
Erban	85.7	42.6	9.2	34.0	32.6	24.1	19.2	5.0	—	—
Roxton	88.8	45.2	7.4	36.8	35.3	20.8	4.5	4.0	—	—
Dasix	84.5	43.3	6.7	34.8	30.8	—	17.8	15.0	—	—
Alaska	80.4	42.7	6.8	36.5	31.1	—	21.8	17.0	—	—
PRAIRIE PROVINCES										
Average of 1-2 years at 5 testing points in Manitoba, 1 in Saskatchewan, and 3 in Alberta										
Ajax	99.0	43.8	7.4	37.7	26.9	24.6	2.5	37.2	9.0	2.3
Exeter	105.7	45.2	6.5	37.1	26.9	26.0	0.8	76.7	31.6	4.6
Victory	106.1	47.0	6.7	38.5	28.7	27.3	38.5	80.0	—	17.6
Vanguard	102.4	44.3	7.0	35.8	26.7	23.2	0.8	71.7	49.4	4.4
Erban	102.6	43.8	6.1	36.2	31.0	—	25.8	58.3	0.5	21.7
Roxton	—	—	—	—	—	—	23.3	68.3	15.4	—
BRITISH COLUMBIA										
Average of 3 years at Saanichton and 1 year at Agassiz										
Ajax	105.5	39.4	10.0	38.9	28.9	—	—	—	—	—
Exeter	108.6	37.6	10.0	37.9	29.4	—	—	—	—	—
Victory	115.9	41.5	10.0	39.9	31.9	—	—	—	—	—
Erban	104.2	39.9	9.6	39.0	35.4	—	—	—	—	—
Dasix	105.0	41.2	9.9	39.4	30.6	—	—	—	—	—
Roxton	115.7	47.5	10.0	38.6	31.2	—	—	—	—	—

Disease Reactions: Rusts—Maritime Provinces, average of three stations in 1943; Ontario and Quebec average of two years at Ottawa, one year at Lennoxville; Western Canada, average of three years at Winnipeg Smuts, average of loose and covered smut, for two years at Winnipeg. Halo-blight, average of two years at Winnipeg.

TABLE 4.—YIELDS OF AJAX AND EXETER COMPARED WITH OTHER VARIETIES IN TESTS CONDUCTED BY THE DOMINION EXPERIMENTAL FARMS AND STATIONS IN EASTERN AND WESTERN CANADA AND IN CO-OPERATIVE TESTS CONDUCTED IN WESTERN ONTARIO BY THE ONTARIO AGRICULTURAL COLLEGE FOR PERIODS OF FROM ONE TO FOUR YEARS

Stations	No. of years tested	Ajax	Exeter	Victory	Banner	Vanguard	Erban	Gopher	Dasix	Alaska	Roxton
Charlottetown	3	56.0	65.8	60.9	—	60.5	61.7	—	60.4	59.8	60.2
Nappan	2	84.4	87.8	87.7	77.0	74.8	80.0	79.6	—	76.2	81.6
Fredericton	3	78.4	80.9	79.1	—	74.2	74.2	—	80.1	—	75.4
St. Anne de la (a)	3	95.1	—	—	90.2	88.9	91.7	—	—	—	101.0
Pocatiere (b)	3	38.0	—	—	33.4	34.7	36.2	—	—	—	35.0
Lennoxville	2	103.8	109.6	—	99.2	108.4	—	—	—	—	—
L'Assomption	1	80.5	—	—	97.1	89.0	88.7	—	—	—	95.9

TABLE 4.—YIELDS OF AJAX AND EXETER COMPARED WITH OTHER VARIETIES IN TESTS CONDUCTED BY THE DOMINION EXPERIMENTAL FARMS AND STATIONS IN EASTERN AND WESTERN CANADA AND IN CO-OPERATIVE TESTS CONDUCTED IN WESTERN ONTARIO BY THE ONTARIO AGRICULTURAL COLLEGE FOR PERIODS OF FROM ONE TO FOUR YEARS—*concluded*

Stations	No. of years tested	Ajax	Exeter	Victory	Banner	Van-guard	Erban	Gopher	Dasix	Alaska	Roxton
Normandin	3	101.6	—	—	88.6	90.4	87.6	—	—	—	107.1
Makamik	2	53.7	—	—	40.6	—	38.6	—	48.1	—	—
Ont. Agric. Coll.	2	54.2	—	—	—	42.0	42.1	—	47.6	42.9	36.7
Harrow	3	71.3	—	—	—	—	—	—	68.7	69.3	—
Ottawa	3	62.7	51.9	51.1	52.1	53.1	59.8	—	53.9	56.4	55.1
Kapuskasing	3	67.5	—	—	—	—	67.4	—	68.3	57.4	—
Fort William	3	107.1	89.7	—	—	93.0	—	—	—	71.4	—
Winnipeg	4	114.0	101.0	88.2	88.1	97.5	89.6	96.1	—	—	—
Morden	4	97.1	82.6	75.0	—	80.0	—	75.8	—	—	—
Brandon	4	112.2	107.5	105.7	—	100.0	—	101.2	—	—	—
Indian Head	4	84.0	90.5	87.6	—	82.0	—	75.8	—	—	—
Swift Current	2	79.1	81.4	74.8	74.1	80.2	—	73.4	—	—	—
Scott	4	49.4	49.0	43.5	—	43.3	—	44.7	—	—	—
Melfort	4	71.6	82.6	79.0	—	73.2	—	70.8	—	—	—
Lethbridge (c)	1	93.6	87.4	87.2	—	98.0	110.4	—	92.1	—	70.7
(d)	1	96.0	128.1	115.8	—	102.7	82.5	—	—	—	80.3
Lacombe	2	118.0	121.4	118.6	—	104.2	93.4	—	117.6	—	—
Beaverlodge	3	75.1	86.2	89.2	87.1	—	—	—	—	—	—
Fort Vermilion	1	95.2	95.6	106.1	—	91.5	91.7	90.5	—	—	—
Agassiz	1	52.9	58.1	58.7	—	—	58.1	52.3	52.8	52.5	59.9
Smithers	1	83.9	—	101.6	—	92.3	89.8	87.3	98.1	—	—
Prince George	1	52.3	58.4	54.4	—	52.7	44.9	46.7	54.5	—	61.2
Saanichton	3	65.3	56.5	60.1	—	—	65.4	—	67.4	—	54.8

NOTE.—a = clay land, b = sandy land; c = dry land, d = irrigated land.

TABLE 5.—SUMMARY OF DATA IN QUESTIONNAIRES RETURNED BY 1,050 FARMERS GROWING AJAX IN 1943

Area	No. of questionnaires returned	Suitability for area expressed in percentage of questionnaires returned			Strength of straw in comparison with other varieties expressed in percentage of questionnaires returned			Yield of Ajax in comparison with other varieties grown under similar conditions		
		Suited	Un-decided	Not suited	Stronger	Similar	Weaker	No. of farms	Ajax	Other varieties
		MANITOBA								
Northern	64	95.3	4.7	0	59.3	30.5	10.2	—	—	—
Central	314	84.8	11.9	3.3	64.8	24.5	10.7	6	58.8	39.7
Southern	112	88.0	12.0	0	68.3	11.9	19.8	4	62.8	46.2
Totals and Averages	490	86.9	11.0	2.1	64.9	22.4	12.7	10	60.4	42.3

TABLE 5.—SUMMARY OF DATA IN QUESTIONNAIRES RETURNED BY 1,050
FARMERS GROWING AJAX IN 1943—*concluded*

Area	No. of questionnaires returned	Suitability for area expressed in percentage of questionnaires returned			Strength of straw in comparison with other varieties expressed in percentage of questionnaires returned			Yield of Ajax in comparison with other varieties grown under similar conditions		
		Suited	Un-decided	Not suited	Stronger	Similar	Weaker	No. of farms	Ajax	Other varieties
Northern Central Southern	SASKATCHEWAN									
	124	78.7	18.0	3.3	60.2	29.6	10.2	7	67.2	52.9
	199	73.3	23.1	3.6	59.8	33.5	6.7	8	60.9	60.2
	101	82.7	17.4	0	59.1	53.3	7.5	9	65.7	54.4
Totals and Averages	425	77.1	20.2	2.7	59.7	32.3	7.9	24	64.5	55.9
Peace River North Central Central Southern	ALBERTA									
	18	70.6	23.5	5.9	50.0	43.8	6.2	—	—	—
	32	73.4	13.3	13.3	55.2	27.6	17.2	2	72.5	63.0
	49	86.7	11.1	2.2	60.5	31.6	7.9	2	45.0	37.5
	15	71.4	7.2	21.4	62.5	25.0	12.5	—	—	—
Totals and Averages	114	78.3	13.2	8.5	57.2	31.9	11.0	4	58.7	50.2
Totals and Averages	WESTERN ONTARIO									
	21	85.7	14.3	0.0	52.6	36.8	10.6	15	48	42

AGRONOMIC AND QUALITY CHARACTERISTICS OF CARLETON DURUM WHEAT GROWN IN THE DURUM WHEAT AREA OF WESTERN CANADA¹

R. F. PETERSON² AND W. O. S. MEREDITH³

Ever since durum wheat became established as a recognized commercial crop in Canada, Mindum has been the leading variety. It has set the standard of quality for durum wheats just as Marquis has done for hard red spring wheats. Mindum has also been outstanding agronomically, but has not had sufficient straw strength for all conditions and, being only moderately resistant to stem rust, has suffered some loss in yield and grade in rust years.

The new variety, Carleton, was developed by the North Dakota Agricultural Experiment Station in co-operation with the Division of Cereal Crops and Diseases, U.S. Department of Agriculture. When grown in the durum wheat area of the United States, it proved to have stronger straw and more stem rust resistance than Mindum and seed of it was distributed to seed growers in that area in 1943.

Seed of Carleton for field tests in Canada was received by the Dominion Laboratory of Cereal Breeding, Winnipeg, in 1941.

The origin of Carleton is described by Smith (1). The original cross, Vernal Emmer \times Mindum, was made in 1930 and many rust resistant strains were obtained but none had the good macaroni-making quality of Mindum. Selected strains were back-crossed with Mindum in 1933, and, after further selection, a second back-cross was made with Mindum in 1936. Carleton is a derivative of this second back-cross.

Smith (1) and Stoa (2) have outlined the characteristics of Carleton wheat. As compared to Mindum, Carleton is described as having more resistance to stem rust; stronger, coarser straw; more erect heads; shorter, plumper kernels; slightly later maturity; and equal semolina quality. Carleton has usually yielded as much as or more than Mindum under rust conditions and slightly less than that variety in non-rust years. In the northern part of North Dakota, adjacent to the durum-growing area of Canada, the yields of the two varieties have been similar although farther south Carleton has yielded relatively less.

The present paper is concerned with a comparison of the performances of Mindum and Carleton wheats in the durum wheat area of Western Canada.

FIELD TESTS

Co-operative rod-row tests of various durum wheats including Mindum and Carleton have been conducted during the years 1941, 1942 and 1943 at the Dominion Laboratory of Cereal Breeding, Winnipeg, and on Dominion Experimental Farms and Stations in the durum wheat area of Western Canada. Each year a uniform set of 16 varieties was tested in balanced lattice field tests. Such a test is comprised of 5 complete blocks

¹ Joint contribution from the Cereal Division, Experimental Farms Service, Dominion Department of Agriculture, and the Grain Research Laboratory, Board of Grain Commissioners for Canada, Winnipeg. Published as Paper No. 130 of the Cereal Division, as Grain Research Laboratory No. 71, and as Paper No. 233 of the Associate Committee on Grain Research. Read before the Western Canadian Society of Agronomy at Saskatoon, Sask., June 22 and 23, 1944.

² Senior Assistant Agricultural Scientist, Dominion Laboratory of Cereal Breeding, Winnipeg, Manitoba.

³ Chemist, Grain Research Laboratory, Board of Grain Commissioners for Canada, Winnipeg.

each containing all 16 varieties and being subdivided into 4 incomplete blocks each consisting of 4 varieties. Each plot consisted of 4 rod-rows sown 9 inches apart, the two centre rows being used for yield determinations. Seed for similar field tests was sent to the North Dakota Agricultural Experiment Station and the tests were conducted at the sub-station at Langdon. All yield data were subjected to an analysis of variance.

One exception to the above plan should be noted. The test at Winnipeg in 1943 was damaged by heavy rains flooding it in early summer, and two complete blocks had to be discarded. The remaining three blocks were treated in analysis as a randomized block test. The variation due to water damage, and the small number of replications resulted in a high experimental error for yield.

Stem rust and leaf rust epidemics were artificially induced at Winnipeg but not at the other Canadian stations.

AGRONOMIC CHARACTERISTICS

The results of the co-operative red-row tests and of special tests are given in summary form in Tables 1 and 2.

Yield

In interpreting the data in Table 1, it should be kept in mind that the yields are, on the whole, considerably higher than average farm yields and that the varietal and minimum significant differences are correspondingly augmented.

Of the 16 yield tests conducted in Canada, all but one (Indian Head, 1941) showed statistically significant differences between varietal mean yields, but only one (Indian Head, 1943) gave a significant difference between Mindum and Carleton, the difference being in favour of Mindum. As the 5% level of significance was used, such an occurrence of one statistically significant difference in 16 comparisons of two varieties might easily be expected if the two varieties were actually of equal yielding ability. It is of interest that considering all 16 differences, however small, Carleton led in yield in 9 tests and Mindum in 7.

An examination of annual and station averages in Table 1 shows Mindum leading in two of the three years and at four of the six Canadian stations, and being 0.6 bushel above Carleton in the three-year average. Under average farm conditions this difference in terms of a fraction of a bushel would probably be reduced both because of lower yields as compared to experimental yields and because a portion of lodged grain harvested by farm machinery may be lost, whereas in the experimental field tests, although Mindum lodged more than Carleton, care was taken to recover all the grain from each plot.

The yield results obtained in the three years of the tests do not appear to establish either of the two named varieties as being superior to the other in yield under the conditions of the tests.

Maturity

Carleton was about a day later in maturing than Mindum. As this difference was due mainly to tests in Manitoba, where most of the rust

occurred, it is possible that the slightly earlier maturity of Mindum was caused, at least in part, by rust.

Straw

The straw of Carleton is definitely stronger and somewhat coarser than that of Mindum. This is true of the "neck" as well as the lower parts of the stem so that the head is erect, rather than nodding as in Mindum.

Height

Carleton averaged slightly taller than Mindum. This again was due to the Manitoba tests, as Mindum averaged slightly taller than Carleton in the Saskatchewan tests. It seems probable that the shortness of straw of Mindum in Manitoba was due to rust damage.

Head Type

Carleton has a head similar to that of Mindum with reddish brown glumes and awns but the awns fall off more readily.

Kernel Type

The kernel of Carleton is shorter, plumper, and somewhat heavier than that of Mindum, with a clear amber colour. The grain sample has a good appearance.

Stem Rust

Under the conditions of the tests Carleton was more resistant than Mindum to stem rust. The average stem rust reaction of Mindum for the three years, however, was quite low and would have been lower had the natural epidemic at Winnipeg not been supplemented with an artificially-induced one.

Leaf Rust

Carleton and Mindum are both highly resistant to leaf rust. Carleton has less resistance than Mindum, but the difference appears to be of no practical importance as it has been evident only under severe artificially-induced leaf rust epidemics.

Bunt

Both varieties appear to be moderately susceptible. It was not possible to determine from this one test whether or not there is a real difference between the two varieties.

Root Rot

Both Carleton and Mindum were more resistant than most of the other varieties tested. The slight difference between the two was not statistically significant.

Kernel Smudge

Carleton has been consistently more susceptible than Mindum to kernel smudge at the various stations.

QUALITY

The macaroni-making qualities of Carleton have been compared with those of Mindum, the standard of quality for durum wheats, by means of laboratory tests on comparable samples of each variety grown in Western Canada in each of the years 1941, 1942, and 1943. These tests were made on samples obtained by compositing the grain from the several stations at which the varieties were grown in the Co-operative Test of Durum Wheat Varieties that is conducted annually under the direction of the Dominion Laboratory of Cereal Breeding, Winnipeg. In addition, semi-commercial and commercial tests were made on samples of each variety grown in Manitoba in 1943. These were composite samples representing grain grown at four points.

The results of the laboratory tests, which were made in the Grain Research Laboratory, Board of Grain Commissioners for Canada, Winnipeg, are quite clear cut, as is shown in Table 3. The two varieties are similar in grade, protein content, ash and pigment content of the wheat, although Carleton tends to be somewhat higher than Mindum in bushel weight and 1,000 kernel weight. Similarities between the varieties in semolina characteristics are also evident, though Carleton tends to be somewhat higher in semolina pigment content, which is an advantage. The best comparison between varieties is, however, the rating of the macaroni. Macaroni quality is judged by appearance; a bright, clear, yellow colour is desirable. In this laboratory, colour determinations are also made on macaroni, and the results for percentage yellow are closely related to the visual placing of the samples. Carleton was rated higher than Mindum in each of the 3 years, as is shown by the visual placing results in Table 3 and confirmed by the values for yellow colour and brightness. It is thus apparent that the higher "kernel smudge" infection of Carleton, as compared with Mindum, which was mentioned in the previous section, did not influence the colour of either semolina or macaroni.

The samples prepared for the commercial tests were tested in the laboratories of General Mills Inc., Minneapolis, and of the Board of Grain Commissioners for Canada; in the semi-commercial scale plant of Pillsbury Flour Mills Co., Minneapolis; and under commercial conditions in the Winnipeg Plant of the Catelli Food Products Ltd. In all these tests Carleton was found to be equal or superior to Mindum in appearance of macaroni. Cooking tests have been made by many individuals on the samples prepared commercially and the consensus of opinion is that Carleton produced somewhat brighter macaroni and that the two varieties do not differ with respect to taste of the cooked macaroni.

There is thus ample evidence to indicate that Carleton grown in Western Canada is at least equal, if not slightly superior, to Mindum in macaroni-making quality. These results agree with those obtained in the United States, where tests have been made on Carleton and Mindum for

several years. Carleton has been found to be equal to or slightly better than Mindum in quality when tested in the durum-wheat growing area of the United States.

SUMMARY AND CONCLUSIONS

Field tests of durum wheat varieties including the new variety, Carleton, and the standard variety, Mindum, were conducted in the durum wheat area of Western Canada at 5 stations in 1941 and 1942, and at 6 stations in 1943, making a total of 16 tests. Carleton gave the higher average yield in 9 tests and Mindum in 7, but in only one case was the difference statistically significant, Mindum having the higher yield.

Comparative data were obtained on days to ripen, strength of straw, height, kernel characteristics, stem rust, leaf rust, bunt, root rot, kernel smudge, and on various factors contributing to macaroni-making quality.

Carleton was distinctly superior to Mindum in strength of straw and in resistance to stem rust, the two characteristics in which improvement has been most needed, but was somewhat more susceptible to kernel smudge. Other differences occurred which however did not appear to be of much practical importance.

The macaroni-making quality of Carleton appeared to be equal if not slightly superior to that of Mindum.

It seems probable that Carleton will be a useful variety in some parts of the durum wheat area of Western Canada particularly in Manitoba where stem rust damage and lodging are more severe on the average than in Saskatchewan. More comprehensive testing and observations on representative farms will be necessary before the adaptation of Carleton to definite zones can be determined.

ACKNOWLEDGMENTS

The writers are indebted to the cerealists at the Dominion Experimental Farms and Stations at Brandon, Morden, Melita, Indian Head and Swift Current for supplying data from their field tests.

Thanks are extended to the members of the Dominion Laboratory of Plant Pathology, Winnipeg, previously mentioned in connection with Table 2, for providing data on disease reactions.

The co-operation of Mr. E. V. Hetherington, General Mills Inc., Minneapolis, Minn.; Mr. R. N. McCaull, Pillsbury Flour Mills Company, Minneapolis, Minn.; and Mr. A. Robitaille and Mr. R. Sampson, Catelli Food Products Ltd., Winnipeg, and Montreal, in making quality tests, is gratefully acknowledged.

REFERENCES

1. SMITH, GLENN S. Two new durum wheat varieties. Bimonthly Bulletin, North Dakota Agricultural Experiment Station, 5 : 4; 2-3. 1943.
2. STOA, T. E. Seed of new rust resistant durums available. Bimonthly Bulletin, North Dakota Agricultural Experiment Station, 6 : 2; 5-6. 1943.

TABLE 1.—YIELD IN BUSHELS PER ACRE OF MINDUM AND CARLETON DURUM WHEATS IN CO-OPERATIVE ROD-ROW TESTS IN THE YEARS 1941-1943, INCLUSIVE

Crop year	Variety	Manitoba				Saskatchewan		North Dakota	Mean all stations	Mean Canadian stations
		Winnipeg	Morden	Brandon	Melita	Indian Head	Swift Current	Langdon		
1941	Mindum	36.0	33.3	40.1	—	33.2	3.6	13.2	26.6	29.2
	Carleton	35.6	35.3	40.7	—	37.4	4.0	24.8	29.6	30.6
		(5.1)*	(6.2)	(3.6)	—	(†)	(1.8)	(2.9)	—	—
1942	Mindum	30.8	73.1	63.7	—	61.0	43.5	40.8	52.2	54.5
	Carleton	35.3	65.2	67.3	—	58.5	41.4	42.0	51.6	53.5
		(7.3)	(6.7)	(6.3)	—	(7.2)	(5.8)	(7.6)	—	—
1943	Mindum	30.9	37.7	40.8	37.3	39.1	14.3	39.7	34.2	33.5
	Carleton	25.0	34.3	41.9	38.8	34.8	14.4	33.8	31.8	31.5
		(14.0)	(4.5)	(8.2)	(7.3)	(2.1)	(7.8)	(5.1)	—	—
Three-year average	Mindum	32.6	48.0	48.2	—	44.4	20.5	31.2	37.7	39.1
	Carleton	32.0	44.9	50.0	—	43.6	19.9	33.5	37.7	38.5

* Figures in brackets indicate minimum significant differences between varietal means at the 5% level of significance.

† Varietal differences not significant, hence no minimum significant difference.

TABLE 2.—AVERAGE AGRONOMIC DATA FROM THE VARIOUS STATIONS IN WESTERN CANADA

Crop year	Variety	Co-operative rod-row tests						Special tests*		
		Days to ripen	Strength of straw 0-10	Height in inches	Stem rust		Kernel smudge† %	Leaf rust %	Bunt %	Root rot %
					A† %	B† %				
1941	Mindum	96.8	7.6	38.0	26.0	4.6	—	4	—	—
	Carleton	98.1	7.9	39.3	1.0	0.2	—	15	—	—
1942	Mindum	113.8	4.9	49.8	35.0	7.2	6.4	trace	—	—
	Carleton	114.6	6.6	49.4	0.4	0.1	9.7	15	—	—
1943	Mindum	112.4	5.4	42.0	3.4	0.6	5.8	0	35	6.4
	Carleton	112.8	7.1	43.2	0.0	0.0	8.6	0	47	5.4
Three-year average	Mindum	107.7	6.0	43.3	21.5	4.1	—	2	—	—
	Carleton	108.5	7.2	44.0	0.5	0.1	—	10	—	—

* Data provided by members of the Dominion Laboratory of Plant Pathology, Winnipeg, as follows:

Leaf Rust, 1941 and 1942: Margaret Newton and B. Peturson.

Bunt: W. Popp.

Root Rot: F. J. Greaney.

† Kernel smudge percentages based on all stations in 1942 and 1943. Data provided by H. A. H. Wallace of the Dominion Laboratory of Plant Pathology, Winnipeg.

‡ A: Stem rust readings from the station having the most rust in a given year. (Winnipeg, 1941 and 1942; Morden, 1943).

B: Average reading for all stations.

TABLE 3.—DATA FOR WHEAT, SEMOLINA, AND MACARONI, SHOWING COMPARISON OF MINDUM AND CARLETON

Crop year	Variety	Wheat					
		Grade	Bushel weight	1,000 Ker-nel wt.	Protein	Ash	Pigment content
			lb.	g	%	%	p.p.m.
1941	Mindum Carleton	2 C.W.	65.0	37.1	15.7	1.59	5.95
		2 C.W.	66.9	42.6	15.7	1.60	5.60
1942	Mindum Carleton	3 C.W.	65.4	41.9	13.1	1.59	6.15
		2 C.W.	67.0	43.7	13.4	1.59	6.10
1943	Mindum Carleton	2 C.W.	67.0	40.9	14.2	1.55	4.70
		2 C.W.	67.0	41.6	14.3	1.54	5.10

		Semolina			
		Yield	Protein	Ash	Pigment
		%	%	%	p.p.m.
1941	Mindum Carleton	54.0	14.7	0.64	4.90
		55.5	14.7	0.59	4.90
1942	Mindum Carleton	53.4	12.4	0.59	4.55
		55.5	12.2	0.54	4.90
1943	Mindum Carleton	53.8	13.1	0.53	4.25
		51.0	13.1	0.51	4.95

		Macaroni					
		Pigment	Colour quality			Bright-ness	Visual placing
			Yellow	Red	White		
		p.p.m.	%	%	%	%	
1941	Mindum Carleton	—	50.9	22.8	26.3	57.0	2
		—	49.6	22.3	28.1	60.5	1
1942	Mindum Carleton	3.50	44.5	20.3	35.2	64.0	2
		3.65	52.1	18.5	29.4	73.0	1
1943	Mindum Carleton	2.70	55.4	21.8	22.8	50.5	2
		3.05	54.4	24.6	21.0	57.0	1

A UNIFORM METHOD OF ANALYSIS FOR SQUARE LATTICE EXPERIMENTS¹

C. H. GOULDEN²

Dominion Laboratory of Cereal Breeding, Winnipeg

Among incomplete block experimental designs for the testing of a large number of varieties the square lattice is one of the most useful. Three square lattice designs are in common use. These are the simple lattice, the triple lattice, and the balanced lattice. Methods of analysis for these have been given by various writers in addition to Yates (2,3,4,5,6) who was responsible for their development. It does not appear to be generally recognized that there are other types such as the quadruple lattice that are possible in this series and that a uniform method of analysis may be used for the entire series of square lattice designs beginning with the simple lattice and ending with the balanced lattice whenever the latter is possible with a given number of varieties. The purpose of this paper is to present such a uniform method of analysis and to point out the uses for types such as the quadruple and quintuple lattice. Recently, the author has received the unpublished manuscript of *Experimental Designs* by W. G. Cochran and Gertrude M. Cox in which similar methods are outlined.

FUNDAMENTALS OF THE SQUARE LATTICE DESIGN

Numbers representing the varieties to be tested in a square lattice experiment can be set up in the form of a square and it is convenient to use two figure numbers in which the first digit represents the row of the square and the second digit the column of the square. Thus for p^2 varieties we will have a square as follows. This square can be used as a starting point for a description of all square lattice designs.

11	12	13	.	.	.	1p
21	22	23	.	.	.	2p
.
p1	p2	p3	.	.	.	pp

The Simple Lattice

In the first replicate we place the varieties together in blocks that occur in the rows of the square, and in the second replicate those that occur in the columns. We require therefore a minimum of 2 replicates. If more are desired the same arrangement is repeated as many times as is necessary in order to obtain sufficient accuracy. The replicates in which

¹ Paper read before the Western Canadian Society of Agronomy at Saskatoon, Sask., June 22 and 23, 1944.

² Officer in charge.

the blocks are made up from the rows of the square can be referred to conveniently as the A group and those from the columns as the B group. The arrangement in the field is to keep all the blocks of one replicate in as compact a form as possible but to randomize the positions of the blocks within the replicates and of the varieties within the blocks.

The Triple Lattice

This is similar to the simple lattice except that a third group is added by making up the blocks from the varieties that occur in the diagonals of the square. For example, with 25 varieties the original square is as follows together with another square in which the varieties in the rows occur in the diagonals of the original square.

<i>Original Square</i>					<i>Square in which Rows are formed from Diagonals of Original</i>				
11	12	13	14	15	11	22	33	44	55
21	22	23	24	25	21	32	43	54	15
31	32	33	34	35	31	42	53	14	25
41	42	43	44	45	41	52	13	24	35
51	52	53	54	55	51	12	23	34	45

The third group may be referred to as group C. The minimum number of replicates is 3 but by repeating all 3 groups we can have 6, 9, or 12 replicates, or any other multiple of 3. As in the simple lattice the replications are arranged as compactly as possible and the blocks randomized within the replicates and the varieties within the blocks.

The Quadruple and Other Partially Balanced Square Lattice Designs

It will be obvious to the reader that a quadruple lattice will result merely from forming another group of blocks, and provided that the orthogonal groups can be formed the series can be continued. However, there are some complications and restrictions in the forming of further groups. In the first place, for certain numbers of varieties such as 36, it is impossible to form more than 3 groups that are orthogonal to each other. On examining groups A, B, and C of a triple lattice it will be noted that the varieties making up any one block are such that one variety is taken from each block in another group. For example, in group C the first row is 11, 22, 33, 44, 55. The first figure of the 2-digit numbers shows that each variety comes from a different row of the original square, and the second figure shows that each variety comes from a different column of the original square. This is what is meant when we say that any one group is orthogonal to all of the other groups. The meaning in terms of the analysis is that the variation in the results for any one group of blocks is independent of the variation in any other group of blocks.

In the second place, the mechanical method we have used for the formation of group C for the triple lattice can be carried forward for the formation of further groups only if the number of varieties is the square of a prime number. It can be used therefore for 25, 49, and 121 varieties

but not for 64, 81, or 100. When the number of varieties is the square of a prime number the method is to write the numbers in the rows of the square for group D that occur in the diagonals of the square for group C. Group E can then be written from the square for group D in a similar manner. We can continue until we have written out $p + 1$ groups. No further orthogonal groups can be obtained. However, if we use $p + 1$ groups our design becomes a Balanced Lattice and possesses properties which justify our placing it in a separate class. If the number of varieties is not the square of a prime number such as 64, 81, or 100, we must make use of a device known as a completely orthogonalized square for writing out groups other than the first two that we have designated by the letters A and B. A completely orthogonalized 4×4 square is given below which will be used to illustrate the method of writing out the groups for 16 varieties.

Completely Orthogonalized 4×4 Square

111	234	342	423
222	143	431	314
333	412	124	241
444	321	213	132

We note first that for a 4×4 square the A and B groups can be written out from the rows and columns of the square without difficulty. The figures in the orthogonalized square are given therefore for groups C, D, and E only. The first digit in each 3-figure number gives us group C as follows. If the orthogonalized square were superimposed on the square of variety numbers the figure 1 would correspond to varieties 11, 22, 33, 44. This would be the first row of the square for group C. The figure 2 would correspond with the varieties 21, 12, 43, 34, and this would be the second row of the square. Finally we would have the square for group C as follows:

11	22	33	44
21	12	43	34
31	42	13	24
41	32	23	14

The second digit in the 3-figure numbers would be used in a similar manner in order to obtain group D, and the third digit to obtain group E. A complete set of the orthogonalized squares so far available are given in *Statistical Tables* by R. A. Fisher and F. Yates (1).

The Balanced Lattice

The method of laying out a balanced lattice experiment will be obvious from the above discussion. We should be careful to note however, that although a partially balanced lattice can be designed with any number of replicates greater than 1, the number of replicates required in order to obtain complete balance is $p + 1$. Thus for 64 varieties we require 9

replications in order to obtain complete balance. This characteristic confines the use of the balanced lattice to rather narrow limits. It is ideal for 25 varieties as ordinarily the experimenter will wish to use about 6 replications. It is also satisfactory for 49 varieties if the material is sufficiently variable to require the use of 8 replications. The advantages of the balanced lattice are that all comparisons between varieties are made with equal accuracy and the method of analysis is somewhat simpler than for the partially balanced lattice. In the latter, varieties that occur together in the same block are compared somewhat more accurately than those that do not occur together in the same block. This difference is greatest in the simple lattice and decreases with the number of groups used. Even for the simple lattice however, the difference in the accuracy of the comparison of varieties in the same and in different blocks is not great enough to be of much concern. The appropriate standard errors for each type of comparison can be worked out if necessary but in general it is satisfactory to use a mean standard error which can be applied to all comparisons without appreciable error. The greater simplicity of the analysis of the balanced lattice designs is not an important factor as the additional time required is quite small and is negligible in proportion to the total amount of time spent in operating the experiment.

METHODS OF ANALYSIS—SQUARE LATTICE EXPERIMENTS

The Partially Balanced Lattice

Although different methods of analysis are usually presented for simple and triple lattice experiments, the following methods will be found to apply to any type of partially balanced lattice and with a few simplifications will also apply to the balanced lattice.

The analysis of the results of a lattice experiment should be kept in mind when the field plans are made. All information relevant to the design should either be entered in the field record or should be kept on file where it will be readily available. As an illustration of the method we shall use the actual results from a quadruple lattice with 25 varieties in 4 replications. The method used can be adapted easily to an example such as a simple lattice with 4 or 6 replications by the introduction of certain modifications that will be described.

A useful first step in the analysis of an incomplete block experiment of the lattice type is to make a preliminary analysis of variance assuming that the test has been laid out in randomized blocks. This does not result in an appreciable loss of time as all the sums of squares will be required in the more complete analysis. If the preliminary analysis shows that the variety differences are significant it will not be necessary to make the more accurate test described later, as the significance of these differences will either be increased or will remain at the same level when the error control due to the blocks has been taken into consideration.

The next step in the analysis is to collect the individual plot yields as in Table 1, re-arranging the variety numbers in a systematic manner corresponding to the squares as originally written out for the groups A, B, C, and D, and writing down the total of each block represented by b . Space is left for entering the values designated by y and $y - rb$, where r

is the number of replications. The variety totals T_v where v represents a variety number, are then obtained and preferably set up in the form of a square as in Table 2, as this will facilitate the determination of the values of y to be entered in Table 1. The first value of y in Table 1 is 575.5 which is the sum of the totals of the varieties that appear in that block. This is the first row total of Table 2. The remaining values of y in replicate 1 are the remaining row totals of Table 2. In replicate 2 the y 's are the column totals of Table 2. In replicate 3 we get y from the diagonal totals of Table 2 taking the first diagonal as the one beginning with variety 11. To get y for replicate 4 we can either re-write the variety totals in the diagonals of Table 2 in the rows of a new table and then take the diagonal totals from this table, or we can merely sum the variety totals as indicated by the variety numbers in the corresponding block. For example, in the first block of group D we sum the totals of varieties 11, 32, 53, 24, and 45, and so forth for any other block. This method is emphasized because in an experiment made up from an orthogonalized square for which the number of varieties is not the square of a prime number, it is the only method of obtaining the values of y for all replicates except those containing groups A and B for which y can always be taken from the rows and columns of the square of variety totals.

The procedure described above for obtaining values of y and the block totals b is the same for all partially balanced lattice designs regardless of the number of groups. It is merely a matter of obtaining the block totals and placing opposite each block total the sum of the totals of the varieties occurring in that block.

In the next stage of the calculations we obtain an analysis of variance in which the variance for blocks is determined in such a way that the effect of varieties is eliminated. Obviously, the variance of the block totals without correction will not represent pure block effect as the varieties that occur in them are not all the same. In order to obtain the corrected block sum of squares there are two procedures that can be followed. The first is to calculate the sum of squares within replicates for the values of $y - rb$, where r represents the number of groups and the number of replicates in the experiment. If we represent $\Sigma(y - rb)$ for one replicate by S , the required sum of squares will be

$$\text{Blocks (SS)} = \frac{\Sigma(y - rb)^2}{pr(r - 1)} - \frac{\Sigma(S^2)}{p^2r(r - 1)} \quad 1$$

A second method is to first calculate for each variety the values that we shall represent by W_v . These will be required later in making the corrections to the variety totals. For any one variety

$$W_v = \Sigma(y_v - rb_v) \quad 2$$

where the summation extends over the r replicates or groups and the subscripts for y and b indicate that in each replicate we take the value of $y - rb$ that corresponds to a given variety v . As an example we have from Table 1

$$W_{23} = -173.9 - 153.2 + 262.4 + 63.0 = -1.7$$

The sum of squares for blocks eliminating varieties is then given by

$$\text{Blocks (SS)} = \frac{\Sigma(W_v^2)}{r(r-1)p^2} \quad 3$$

In choosing between the two methods of obtaining the block sums of squares we should note that the volume of work will depend on the number of values to be squared and the number of operations to be performed. formula 1 requires that we square $r(p+1)$ values, perform 2 divisions and 1 subtraction. For formula 2 we have to square p^2 values but there is only 1 division and no subtractions. The second method is the most straightforward and is recommended for all cases except where r is small in proportion to p . It has the additional advantage that it is the same procedure as is followed for obtaining the block sum of squares in analysing a balanced lattice.

The sums of squares for replicates, varieties, and total are taken from the preliminary analysis. The sum of squares for intrablock error is then obtained by the subtraction of replicates, blocks and varieties from the total. We can now set up an analysis of variance according to the following scheme.

	DF	Mean Square
Replicates	$r - 1$	
Blocks, eliminating Varieties	$r(p - 1)$	B
Varieties	$p^2 - 1$	
Intrablock error	$(p - 1)(rp - p - 1)$	E
Total	$rp^2 - 1$	

From the above analysis we note the relative values of B and E . If B is not greater than E we can assume that error control by means of the blocks has not been efficient and we will discard the more elaborate analysis and carry on as if the experiment had been laid out in randomized blocks. This occurs only in exceptional cases. If B is smaller than E it is justifiable to assume that the situation is the same as if B is equal to E , although if there is a considerable discrepancy in this direction one would be inclined to look for errors, either in the computations or in the handling of the experiment. Generally, we find that B is at least 2 or 3 times as great as E and we proceed as follows, to obtain the corrected variety means and the standard error of differences between two variety means. The first step is to calculate the coefficient λ as follows

$$\lambda = \frac{B - E}{B} \quad 4$$

Then a corrected variety total is

$$rt_v = T_v + \left\{ \frac{\lambda}{(r-1)p} \right\} W_v \quad 5$$

As pointed out above, in a partially balanced experiment, all comparisons are not made with equal precision; that is, varieties that occur in the same block will be tested more accurately than varieties that do not

occur in the same block. For varieties occurring in the same block the variance of a difference between two means is

$$V_s = \frac{2E}{r} \left\{ 1 + \frac{B - E}{pB} \right\} = \frac{2E}{r} \left\{ 1 + \frac{\lambda}{p} \right\} \quad 6$$

For varieties not occurring in the same block the variance is

$$V_d = \frac{2E}{r} \left\{ 1 + \left(\frac{r}{r-1} \right) \frac{B - E}{pB} \right\} = \frac{2E}{r} \left\{ 1 + \left(\frac{r}{r-1} \right) \frac{\lambda}{p} \right\} \quad 7$$

A mean variance for all comparisons which can be used without appreciable error is

$$V_m = \frac{2E}{r} \left\{ 1 + \left(\frac{r}{r-1} \right) \frac{B - E}{(p+1)B} \right\} \frac{2E}{r} \left\{ 1 + \frac{rp}{(p+1)(r-1)} \left(\frac{\lambda}{p} \right) \right\} \quad 8$$

Finally, if it is considered sufficiently important, the variety sum of squares can be adjusted in order to obtain a variety variance which can be tested against the intrablock error. We first calculate the block variance without adjusting for the effect of varieties. In other words this is calculated directly from the block totals. Representing this sum of squares by B_u and the block sum of squares as calculated above after eliminating the effect of varieties by B_a , the adjustment to the variety sum of squares is given by

$$- \lambda \left\{ \left(\frac{rB}{rB - E} \right) B_u - B_a \right\} \quad 9$$

The minus sign indicates that the quantity obtained by this formula is subtracted from the variety sum of squares obtained directly from the variety totals. The resulting sum of squares will yield a variety variance that can be tested directly against the intrablock error.

Repetition of Groups in Partially Balanced Lattice Experiments

A design very frequently used is the simple or triple lattice in which the groups are repeated in order to obtain the necessary number of replications. For 6 replications the groups of a simple lattice must be repeated 3 times and in a triple lattice they must be repeated twice. In order to analyze such experiments our methods must be modified slightly.

The main difference in method is in the calculation of the sum of squares for blocks from which the effect of varieties has been eliminated. For example, if we have a simple lattice in which there are 3 replicates of each group, the block totals can be set up as in the following diagram.

<i>Block Repetitions</i>				<i>Block Repetitions</i>			

Thus block 1 of Group A is repeated 3 times and from the differences among such blocks we can obtain an estimate of the block effect directly without adjusting for the effect of varieties, which if there are n repetitions, will be represented in each group by $(n - 1)(p - 1)$ DF , and in an experiment with k groups by a total of $k(n - 1)(p - 1)$ DF . Since r (number of replicates) = kn , this simplifies to $(r - k)(p - 1)$ for the general case. The method of obtaining the sum of squares will be obvious to anyone familiar with the elements of the analysis of variance. It is exactly similar to the procedure for calculating the sum of squares for an interaction in a $p \times n$ fold table.

The analysis of variance for a partially balanced lattice experiment with repetitions of the groups will be of the following form. It will be noted

Form of Analysis of Variance Where Groups are Repeated

	DF	MS
Replicates	$r - 1$	
Blocks	$r(p - 1)$	$\left\{ \begin{array}{ll} (r - k)(p - 1) & \text{Component a} \\ k(p - 1) & \text{Component b} \end{array} \right\} B$
Varieties	$p^2 - 1$	
Intrablock error	$(p - 1)(rp - p - 1)$	E
Total	$rp^2 - 1$	

that the sum of squares for blocks is divided into components **a** and **b** where **a** represents the component that is obtained directly as described above. Component **b** is determined in the same manner as in an experiment that is not repeated after the totals for similar blocks have been combined. This means that the formula for the sum of squares corresponding to 3 above is

$$\text{Component b} = \frac{\Sigma(W_v^2)}{r(k - 1)p^2} \quad 10$$

where W_v is as in formula 2 except that b_v is a total of similar blocks within a group.

In determining the value of λ we should note that the fundamental formula is

$$\lambda = (k - 1) \left\{ \frac{w - w'}{(k - 1)w + w'} \right\} \quad 11$$

where

$$w = \frac{1}{E} \quad w' = \frac{r - 1}{rB - E} \quad 12$$

Substituting for w and w' in 11 we get the formula for λ when the groups are repeated, in a form which is more suitable for calculation.

$$\lambda = (k - 1) \left\{ \frac{r(B - E)}{r(k - 1)B + (r - k)E} \right\} \quad 13$$

The equation for the corrections to the variety totals will be essentially the same as 5. Thus, a corrected total is given by

$$rt_v = T_v + \left\{ \frac{\lambda}{(k-1)p} \right\} W_v \quad 14$$

Finally, the variances for differences between means of varieties can be determined by using formulas 6, 7, and 8, with the exception that r is substituted for k outside the main bracket but not inside the bracket.

One characteristic of experiments with repeated groups is that if there are sufficient degrees of freedom available for the estimate of B from component \mathbf{a} alone, it is unnecessary to determine component \mathbf{b} . We will then have

$$w = \frac{1}{E} \qquad w' = \frac{1}{B} \quad 15$$

where B represents component \mathbf{a} . Further

$$\lambda = \frac{(k-1)(B-E)}{(k-1)B+E} \quad 16$$

In general it can be taken that a simple lattice with 6 replications or a triple lattice with 9 replications is sufficiently large to justify using component \mathbf{a} only in order to estimate the value of B .

In order to make the more accurate test of the variety differences we calculate the adjustment to the variety sum of squares as follows.

$$\text{Adjustment} = -\lambda \left[\left\{ \frac{rB + (r-2)E}{rB-E} \right\} B_u - B_a \right] \quad 17$$

Where B_u is the unadjusted sum of squares calculated from the totals by groups of similar blocks and B_a is component \mathbf{b} .

The Balanced Lattice

The method of analysis is similar to that for the partially balanced lattice with certain simplifications. In the first place the values of y are more easily computed. For any one variety, y_v can be equated to $pT_v + G$, where G is the grand total of the experiment. Therefore W_v is given by

$$W_v = pT_v + G - rb_v \quad 18$$

In the second place, since all comparisons are made with equal precision, there will be only one variance for differences between means of varieties, which is given by formula 6.

A third simplification arises in making the F test of the adjusted variety variance. The sum of squares for varieties adjusted for blocks is given by

$$\text{Adjusted variety (SS)} = \frac{\frac{\sum (rt_v)^2}{r} - \frac{G^2}{rp^2}}{1 + \frac{\lambda}{p}} \quad 19$$

In other words we determine the sum of squares of the corrected variety totals and divide by $1 + \lambda/p$.

Example 1. Quadruple Lattice—Partially Balanced Lattice with 4 Groups.

In this example

$$v \text{ (number of varieties)} = p^2 = 25$$

$$r \text{ (number of replications)} = k \text{ (number of groups)} = 4$$

The procedure can be carried out in steps as enumerated below.

1. Individual plot yields are taken directly from the field records and entered in Table 1. Note that the variety numbers are arranged in systematic order in accordance with the original squares of variety numbers that were written out before the test was randomized. The systematic order is not essential but is a convenience in calculation. If a preliminary test of the variety variance is to be made we would proceed directly to a determination of the variety totals as in step 3 below.

2. Determine block totals and enter in Table 1. These are indicated by b .

3. Obtain variety totals from Table 1 and enter them in the form of a square as in Table 2. Determine row and column totals of this table.

4. Enter values of y in Table 1 and calculate $y - rb$ for each block. In replicate 1 the required values of y are the row totals of Table 2, and in replicate 2 they are the column totals. For the third replicate we can obtain y from the totals of the diagonals of Table 2, beginning with the variety 11 in order to obtain the first total. If Table 2 is re-written so that the numbers in the diagonals form the rows of the new table, the totals of the diagonals of this table will give y for replicate 4. With a little practice the required totals can be obtained from Table 2 directly without re-writing. Note that for any one block the corresponding y is the sum of totals of the varieties that occur in that block. Thus we can obtain y for any block simply by summing the required variety totals and it is not necessary to follow the method outlined above.

5. Calculate W_v for each variety and enter in Table 3. For each variety W_v is the sum of the corresponding values of $y - rb$. Thus for variety 23 we have

$$W_{23} = -173.9 - 153.2 + 262.4 + 63.0 = -1.7$$

6. Calculate the sum of squares for blocks from which the effect of varieties has been eliminated, using formula 2 or 3. For formula 3 we have

$$\text{Blocks (SS)} = \frac{282,806.58}{300} = 942.689$$

7. If a preliminary analysis of variance has not been carried out, obtain at this point the total sum of squares and the sums of squares for replicates and varieties, using individual yields, replicate totals, and variety totals. In this example.

$$\text{Replicate (SS)} = \frac{2,319,929.88}{25} - \frac{(2990.2)^2}{300} = 3384.235$$

$$\text{Varieties (SS)} = \frac{364,310.820}{4} - \frac{(2990.2)^2}{300} = 1664.745$$

$$\text{Total (SS)} = 96,389.900 - \frac{(2990.2)^2}{300} = 6976.940$$

The sum of squares for intrablock error can be obtained by subtraction of blocks, replicates, and varieties from the total.

8. The analysis of variance can now be set up and the values of B and E calculated. In this example the analysis is as follows

	SS	DF	MS
Replicates	3384.235	3	
Blocks, eliminating varieties	942.689	16	58.9181 = B
Varieties, ignoring blocks	1664.745	24	
Intrablock error	985.271	56	17.5941 = E
Total	6976.940	99	

We note that B is considerably larger than E so we decide that the incomplete blocks have provided reasonable error control and we proceed to complete the analysis.

9. Calculate λ and set up the equation for obtaining the corrected variety totals or corrected variety means. Here, we have

$$\lambda = \frac{58.9181 - 17.5941}{58.9181} = 0.701,380$$

and

$$\frac{\lambda}{(r-1)p} = \frac{0.701,380}{15} = 0.046,759$$

Applying the equation for obtaining the corrected variety totals to variety 12 we have

$$rt_{12} = 132.5 + 0.046,759 \times 49.7 = 105.81$$

As a check on the work it is useful to take the corrected totals to at least 2 decimal places. The total of these should then check very closely with the grand total as previously determined.

10. Calculate the variances and standard errors for differences between means of varieties. The mean variance for such comparisons will in nearly all cases be sufficient but the calculation of the others is given below for reference

$$\begin{aligned} V_s &= \frac{2 \times 17.5941}{4} \left(1 + \frac{0.701,380}{5} \right) \\ &= 8.797,05 \times 1.14028 = 10.0311 \\ V_d &= 8.797,05 \left(1 + \frac{4}{3} \times 0.140,28 \right) = 10.4424 \\ V_m &= 8.797,05 \left(1 + \frac{10}{9} \times 0.140,28 \right) = 10.1683 \end{aligned}$$

The square roots of the above variances will of course give the required standard errors.

11. Finally, we can if we wish make an accurate test of the significance of the variety variance adjusted for the effect of blocks. This step is not essential in that we could make a test of the unadjusted variety variance as indicated in step 1 above, assuming that the experiment had been laid out in randomized blocks, and this test would be sufficient in most cases. The more accurate test however, is easily carried out and generally the experimenter will wish to do it in order to have his records complete.

Following formula 9 we first calculate B_u , the unadjusted sum of squares for blocks. In this example

$$B_u = \frac{470,421.08}{5} - \frac{2,319,929.88}{25} = 1287.021$$

Also

$$\frac{rB}{rB - E} = \frac{4 \times 58.9181}{4 \times 58.9181 - 17.5941} = 1.080,678$$

The adjustment to the variety sum of squares is then

$$- 0.701,380 \{ (1.080,678 \times 1287.021) - 942.689 \} = - 314.335$$

Subtracting 314.335 from 1664.745 we have 1350.41 and the adjusted variety variance is $1350.41/24 = 56.267$, and $F = 56.267/17.5941 = 3.20$, which can be compared with a 5% point of 1.72 for 24 and 56 degrees of freedom.

Example 2. Partially Balanced Lattice (Simple) with Groups Repeated

$$\text{Number of varieties } (v) = p^2 = 16$$

$$\text{Number of groups } (k) = 2$$

$$\text{Number of replications } (r) = 2k = 4$$

The procedure of the analysis can be carried out in steps comparable with those of Example 1, which should be worked out before attempting Example 2.

1. The individual plot yields are taken directly from the field records and entered in Table 4. This table is comparable to Table 1 but note that replicates 1 and 3 belong to the same group and the yields by varieties and blocks are combined in the column headed group A. Similarly, the results for replicates 2 and 4 are combined in the column headed group B. After completing Table 4 we can if we wish obtain the variety totals as in 3 below and make the preliminary analysis assuming that the test has been laid out in randomized blocks.

2. Obtain all block totals and corresponding totals by groups which are represented by b . The differences between the totals of corresponding blocks should also be entered in Table 4 at this stage. These are to be used later in the calculation of component a for blocks.

3. Determine variety totals and enter in the form of a square as in Table 5, and obtain row and column totals.

4. Enter the values of y in Table 4. In group A these are the row totals of Table 5, and in group B they are the column totals. Note that 1558.8 in block 1 of group A is the sum of the totals for the varieties that

occur in that block. Consequently, regardless of the number of groups in the experiment y can be obtained by summing the totals for the varieties that occur in a given block. In a simple lattice y values are always given by the row and column totals of Table 5, and in a triple lattice by the totals of the rows, columns, and diagonals. After entering y we determine the required values of $y - kb$ and enter them immediately below.

5. Calculate W_v for each variety and enter in Table 6. For each variety W_v is the sum of the corresponding values of $y - kb$. Thus for variety 32 we have

$$W_{32} = 76.4 + 65.9 = 142.3$$

6. Calculate the sums of squares for blocks. It will be necessary to determine both component **a** and component **b**. If the differences between comparable blocks are represented by d and their totals for each group by D , the sum of squares for component **a** is given in this example by

$$\begin{aligned} \text{Component a} &= \frac{\Sigma(d^2)}{2p} - \frac{\Sigma(D^2)}{2p^2} \\ &= \frac{15,899.65}{8} - \frac{28,040.05}{32} = 1111.204 \end{aligned}$$

Note that if there had been more than 2 replications in each group it would have been necessary to calculate component **a** by the method described on page 12.

Component **b** can be calculated from formula 1 or 3. In formula 3 the divisor is $r(k-1)p^2$ in place of $r(r-1)p^2$. Using formula 3 in this example we have

$$\text{Component b} = \frac{96,833.58}{64} = 1513.025$$

Combining components **a** and **b** we have 2624.23 as the sum of squares for blocks from which the effect of varieties has been eliminated.

7. If a preliminary analysis has not been carried out, calculate at this stage the total sum of squares and the sums of squares for replicates and varieties, and obtain the sum of squares for intrablock error by subtraction from the total.

8. Set up the analysis of variance as follows and determine the values of B and E .

	SS	DF	MS
Replicates	882.95	3	
Blocks, eliminating varieties	2624.23	12	218.686 = B
Varieties, ignoring blocks	7389.88	15	
Intrablock error	3584.61	33	108.624 = E
Total	14,481.67	63	

Since B is about twice as large as E we can assume that the lattice design has contributed to the accuracy of the experiment and we proceed to the completion of the analysis.

9. Calculate λ from formula 13 and set up the equation for obtaining the corrected variety totals as in formula 14. In this example

$$\lambda = \frac{2(218.686 - 108.624)}{2 \times 218.686 + 108.624} = 0.403,160$$

and

$$\frac{\lambda}{(k-1)p} = \frac{0.403,160}{4} = 0.100,790$$

To obtain the corrected total for variety 42

$$rt_{42} = 289.6 + 0.100,790 \times 77.8 = 297.44$$

10. The variances of differences between means of varieties are

$$V_s = \frac{2 \times 108.624}{4} \left(1 + \frac{0.403,160}{4} \right) = 54.3120 \times 1.100,790 = 59.7861$$

$$V_d = 54.3120 \left\{ 1 + \left(\frac{2}{1} \right) \times 0.100,790 \right\} = 65.2602$$

$$V_m = 54.3120 \left\{ 1 + \left(\frac{8}{5} \right) \times 0.100,790 \right\} = 63.0704$$

and the square roots of these give the required standard errors.

11. In order to make an accurate test of the significance of the variety variance after adjustment for the effect of the blocks we calculate B_u , which is the unadjusted sum of squares for component b, as follows.

$$\frac{(820.2)^2 + (728.9)^2 + \dots + (790.4)^2}{8} - \frac{(2985.0)^2 + (3005.7)^2}{32} = 2893.055$$

Also

$$\frac{rB + (r-2)E}{rB - E} = \frac{4 \times 218.686 + 2 \times 108.624}{4 \times 218.686 - 108.624} = -1.425,36$$

Then the adjustment is

$$-0.403,160 \{ (1.425,36 \times 2893.055) - 1513.025 \} = 1052.498$$

and the adjusted variety sum of squares is $7389.88 - 1052.50 = 6337.38$. The adjusted variety variance is $6337.38/15 = 422.49$ and F is $422.49/108.62 = 3.89$.

Example 3. Balanced Lattice. In this example

number of varieties (v) = $p^2 = 25$

number of replicates (r) = $p + 1$ = number of groups (k) = 6.

The procedure is identical with that for partially balanced lattices without repetition of groups, except for a few simplifications. Enumerating the steps we have

1. Individual plot yields are taken directly from the field record and entered in Table 7. The block and replicate totals are determined and entered in the same table.

2. Determine the variety totals from Table 7 and enter opposite the variety numbers in Table 8. If we wish to make a preliminary analysis of variance assuming the test laid out in randomized blocks, it would be carried out at this stage.

3. Calculate W_v for each variety using formula 18. Thus for variety 24 we would have

$$W_{24} = 5 \times 257.3 + 6245.2 - 6(205.7 + 212.4 + \dots 189.1) = -24.1$$

4. Calculate the sum of squares for blocks from which variety effects have been eliminated using formula 3.

$$\text{Blocks (SS)} = \frac{921,964.14}{750} = 1229.29$$

5. The remaining sums of squares are determined and the analysis of variance set up from which B and E are calculated.

	SS	DF	MS
Replicates	416.51	5	
Blocks, eliminating varieties	1229.29	24	51.220 = B
Varieties, ignoring blocks	2431.48	24	
Intrablock error	1601.46	96	16.682 = E
Total	5678.74	149	

6. Compute the value of λ using formula 4, and set up equation 5 for obtaining the corrected variety totals.

$$\lambda = \frac{51.220 - 16.682}{51.220} = 0.674,307$$

and

$$\frac{\lambda}{(r-1)P} = \frac{0.674,307}{25} = 0.026,972,3$$

Then $rt_{24} = 257.3 - 0.026,972,3 \times 24.1 = 256.65$. These are entered in Table 8 and from them we determine the corrected variety means.

7. The variance of a difference between two variety means is

$$V_s = \frac{2 \times 16.682}{6} \left(1 + \frac{0.674,307}{5} \right) = 6.3108$$

8. In order to make an accurate test of the variety variance we require the sum of squares of the corrected variety totals. This is divided by $1 + \lambda/p$, giving the adjusted sum of squares for varieties directly.

$$\text{Corrected variety totals (SS)} = \frac{1,573,757.703}{6} - \frac{(6245.2)^2}{150} = 2276.13$$

This is divided by $1 + \lambda/p$ which has been determined above to be 1.134,86. We have, $2276.13/1.134,86 = 2005.65$, and the mean square is $2005.65/24 = 83.568$. Then $F = 83.568/16.682 = 5.01$.

TABLE 1—INDIVIDUAL PLOT YIELDS, BLOCK TOTALS, AND VALUES OF y AND $y - rb$ QUADRUPLE LATTICE WITH 25 VARIETIES IN 4 REPLICATIONS

Block no.	Repl. 1		Repl. 2		Repl. 3		Repl. 4	
	Var. no.	Group A	Var. no.	Group B	Var. no.	Group C	Var. no.	Group D
1	11	27.4	11	37.2	11	23.4	11	20.0
	12	38.6	21	37.5	22	19.0	32	20.8
	13	29.1	31	18.0	33	11.8	53	27.6
	14	21.3	41	42.2	44	13.3	24	23.9
	15	34.1	51	43.3	55	18.9	45	25.5
b		150.5		178.2		86.4		117.8
y		575.5		578.8		584.4		576.8
$y - rb$		-26.5		-134.0		238.8		105.6
2	21	36.6	12	40.9	21	22.5	21	23.8
	22	46.1	22	44.2	32	22.7	42	38.5
	23	44.7	32	36.7	43	25.0	13	25.4
	24	40.6	42	34.8	54	22.3	34	30.1
	25	37.3	52	35.8	15	34.0	55	29.8
b		205.3		192.4		126.5		147.6
y		647.3		616.3		628.5		597.6
$y - rb$		-179.3		-153.3		122.5		7.2
3	31	16.7	13	31.6	31	18.0	31	21.0
	32	30.0	23	45.0	42	19.3	52	21.5
	33	28.0	33	37.8	53	25.0	23	34.5
	34	33.3	43	40.8	14	19.9	44	21.0
	35	26.2	53	36.4	25	28.3	15	32.5
b		134.2		191.6		110.5		130.5
y		516.6		613.2		536.4		585.0
$y - rb$		-20.2		-153.2		94.4		63.0
4	41	40.1	14	24.4	41	22.7	41	39.2
	42	25.6	24	28.0	52	25.0	12	39.9
	43	39.7	34	38.6	13	22.4	33	28.4
	44	36.4	44	38.8	24	25.4	54	28.2
	45	37.3	54	36.0	35	24.4	25	32.7
b		179.1		165.8		119.9		168.4
y		622.5		562.0		594.5		640.7
$y - rb$		-93.9		-101.2		114.9		-32.9
5	51	33.4	15	39.3	51	27.8	51	28.0
	52	38.8	25	35.6	12	13.1	22	25.0
	53	35.0	35	31.2	23	16.6	43	28.4
	54	37.6	45	37.3	34	21.9	14	21.0
	55	38.4	55	39.5	45	16.6	35	21.0
b		183.2		182.9		96.0		123.4
y		628.3		619.9		646.4		590.1
$y - rb$		-104.5		-111.7		262.4		96.5
Replicate totals		852.3		910.9		539.3		687.7

NOTE—Check calculations from $\Sigma(y - rb)$ over all blocks = 0.

TABLE 2.—VARIETY TOTALS (T_v) — *Quadruple Lattice*

Variety numbers	11	12	13	14	15	Row totals
Variety totals	108.0	132.5	108.5	86.6	139.9	575.5
Variety numbers	21	22	23	24	25	
Variety totals	120.4	134.3	140.8	117.9	133.9	647.3
Variety numbers	31	32	33	34	35	
Variety totals	73.7	110.2	106.0	123.9	102.8	516.6
Variety numbers	41	42	43	44	45	
Variety totals	144.2	118.2	133.9	109.5	116.7	622.5
Variety numbers	51	52	53	54	55	
Variety totals	132.5	121.1	124.0	124.1	126.6	628.3
Column totals	578.8	616.3	613.2	562.0	619.9	2990.2 = G

TABLE 3.—VALUES BY VARIETIES OF W_v , rt_v , AND t_v —QUADRUPLE LATTICE

Variety numbers	W_v	rt_v	t_v
11	183.9	116.60	29.2
12	49.7	134.82	33.7
13	-57.6	105.81	26.4
14	63.2	89.56	22.4
15	47.3	142.11	35.5
21	-178.2	112.07	28.0
22	8.1	134.68	33.7
23	-1.7	140.72	35.2
24	-54.6	115.35	28.8
25	-224.1	123.42	30.8
31	3.2	73.85	18.5
32	54.6	112.75	28.2
33	32.5	107.52	26.9
34	148.2	130.83	52.7
35	79.5	106.52	26.6
41	-145.9	137.38	34.3
42	-145.6	111.39	27.3
43	-28.1	132.59	33.1
44	106.7	114.49	28.6
45	162.4	124.29	31.1
51	120.4	138.13	34.5
52	-79.9	117.36	29.3
53	-57.7	121.30	30.3
54	-116.1	118.67	29.7
55	29.8	127.99	32.0
Sum =	0	2990.2	

TABLE 4.—INDIVIDUAL PLOT YIELDS, BLOCK TOTALS, GROUP TOTALS AND VALUES OF y , AND $y - rb$. SIMPLE LATTICE WITH 16 VARIETIES IN 4 REPLICATIONS

Block no.	Var. no.	Repl. 1	Repl. 3	Group A	Var. no.	Repl. 2	Repl. 4	Group B
1	11	93.6	105.0	198.6	11	76.0	85.0	161.0
	12	99.5	97.0	196.5	21	113.5	115.6	229.1
	13	113.3	115.2	228.5	31	84.4	101.5	185.9
	14	100.8	95.8	196.6	41	87.5	98.6	186.1
Totals		407.2	413.0	820.2 (b)		361.4	400.7	762.1 (b)
		-5.8 (d)		1558.8 (y)		-39.3 (d)		1529.2 (y)
				-81.6 (y - kb)				5.0 (y - kb)
2	21	109.0	102.7	211.7	12	98.1	78.2	176.3
	22	90.6	95.3	185.9	22	78.2	83.1	161.3
	23	79.4	106.6	186.0	32	93.0	93.6	186.6
	24	73.0	72.3	145.3	42	48.8	73.7	122.5
Totals		352.0	376.9	728.9 (b)		318.1	328.6	646.7 (b)
		-24.9 (d)		1471.8 (y)		-10.5 (d)		1359.3 (y)
				14.0 (y - kb)				65.9 (y - kb)
3	31	76.1	105.0	181.1	13	113.1	102.5	215.6
	32	61.6	101.5	163.1	23	75.9	91.7	167.6
	33	80.6	93.0	173.6	33	104.5	78.2	182.7
	34	88.5	103.3	191.8	43	129.7	110.9	240.6
Totals		306.8	402.8	709.6 (b)		423.2	383.3	806.5 (b)
		-96.0 (d)		1495.6 (y)		39.9 (d)		1606.1 (y)
				76.4 (y - kb)				-6.9 (y - kb)
4	41	89.6	86.1	175.7	14	71.6	114.1	185.7
	42	76.4	90.7	167.1	24	92.5	92.4	184.9
	43	100.6	110.9	211.5	34	117.8	113.0	230.8
	44	80.2	91.8	172.0	44	92.6	96.4	189.0
Totals		346.8	379.5	726.3 (b)		374.5	415.9	790.4 (b)
		-32.7 (d)		1464.5 (y)		-41.4 (d)		1496.1 (y)
				11.9 (y - kb)				-87.7 (y - kb)
Replicate Totals and Group Totals		1412.8	1572.2	2985.0		1477.2	1528.5	3005.7
		-159.4 (D)		5990.7 (Σy) = G		-51.3 (D)		5990.7 (Σy) = G
				20.7 (S)				-20.7 (S)

TABLE 5.—VARIETY TOTALS (T_v). SIMPLE LATTICE WITH 16 VARIETIES IN 4 REPLICATIONS

Variety numbers	11	12	13	14	Row totals
Variety totals	359.6	372.8	444.1	382.3	1558.8
Variety numbers	21	22	23	24	
Variety totals	440.8	347.2	353.6	330.2	1471.8
Variety numbers	31	32	33	34	
Variety totals	367.0	349.7	356.3	422.6	1495.5
Variety numbers	41	42	43	44	
Variety totals	361.8	289.6	452.1	361.0	1464.5
Column totals	1529.2	1359.3	1606.1	1496.1	5990.7

TABLE 6—VALUES BY VARIETIES OF W_v , rt_v , AND t_v . SIMPLE LATTICE WITH 16 VARIETIES IN 4 REPLICATIONS

Variety Numbers	W_v	rt_v	t_v
11	-76.6	351.88	88.0
12	-15.7	371.22	92.8
13	-88.5	435.18	108.8
14	-166.3	365.54	91.4
21	19.0	442.72	110.7
22	79.9	355.25	88.8
23	7.1	354.32	88.6
24	-70.7	323.07	80.8
31	81.4	375.20	93.8
32	142.3	364.04	91.0
33	69.5	363.30	90.8
34	-8.3	421.76	105.4
41	16.9	363.50	90.9
42	77.8	297.44	74.4
43	5.0	452.60	113.2
44	-72.8	353.66	88.4
Totals	0	5990.7	

TABLE 7.—INDIVIDUAL PLOT YIELDS AND BLOCK AND REPLICATE TOTALS. BALANCED LATTICE WITH 25 VARIETIES

Replicate 1		Replicate 2		Replicate 3		Replicate 4		Replicate 5		Replicate 6	
11	34.5	11	39.1	11	42.3	11	42.2	11	37.2	11	40.0
12	48.6	21	41.5	22	41.1	32	44.8	42	33.9	52	46.3
13	45.9	31	35.9	33	36.0	53	34.7	23	32.0	43	40.2
14	45.1	41	44.6	44	44.2	24	43.7	54	42.7	34	46.7
15	44.6	51	43.2	55	44.1	45	40.0	35	40.6	25	36.6
b_v	218.7		204.3		207.7		205.4		186.4		209.1
21	51.1	12	43.2	21	34.6	21	43.7	21	50.8	21	48.8
22	46.9	22	46.5	32	44.3	42	23.9	52	47.4	12	46.2
23	31.0	32	49.6	43	44.7	13	39.1	33	37.0	53	44.3
24	42.4	42	45.1	54	38.3	34	38.5	14	46.7	44	47.3
25	34.3	52	48.8	15	36.7	55	38.5	45	47.2	35	49.2
b_v	205.7		233.2		198.6		183.7		229.1		235.8
31	32.7	13	49.8	31	30.9	31	34.9	31	26.5	31	31.4
32	36.6	23	33.4	42	46.1	52	42.0	12	45.8	22	40.8
33	43.3	33	41.4	53	42.6	23	30.6	43	39.5	13	40.8
34	49.2	43	44.0	14	46.6	44	41.5	24	40.2	54	35.3
35	35.1	53	41.5	25	31.0	15	44.6	55	42.3	45	32.3
b_v	196.9		210.1		197.2		193.6		194.3		180.6

TABLE 7.—INDIVIDUAL PLOT YIELDS AND BLOCK AND REPLICATE TOTALS.
BALANCED LATTICE WITH 25 VARIETIES—*Concluded*

Replicate 1		Replicate 2		Replicate 3		Replicate 4		Replicate 5		Replicate 6	
41	50.5	14	46.6	41	50.1	41	50.9	41	23.6	41	41.4
42	40.2	24	40.8	52	46.4	12	46.7	22	53.2	32	39.3
43	46.9	34	40.0	13	52.8	33	41.4	53	38.2	23	29.8
44	48.3	44	37.6	24	51.4	54	43.1	34	44.6	14	36.0
45	55.0	54	47.4	35	51.7	25	35.6	15	43.1	55	35.8
<i>b_v</i>	240.9		212.4		252.4		217.7		202.7		182.3
51	44.6	15	44.8	51	46.9	51	40.1	51	31.6	51	42.4
52	48.8	25	37.0	12	50.8	22	48.8	32	35.5	42	38.2
53	48.8	35	44.6	23	34.4	43	40.0	13	39.5	33	34.9
54	41.2	45	34.4	34	46.8	14	48.3	44	35.7	24	38.8
55	41.1	55	44.0	45	46.3	35	44.2	25	29.1	15	34.8
<i>b_v</i>	224.5		214.8		225.2		221.4		171.4		189.1
Replicate Totals	1086.7		1074.8		1081.1		1021.8		983.9		996.9

TABLE 8.—VALUES BY VARIETIES OF T_v , W_v , rt_v , AND t_v . BALANCED LATTICE WITH
25 VARIETIES

Variety numbers	T_v	W_v	rt_v	t_v
11	235.3	32.1	236.16	39.4
12	281.3	−297.7	273.27	45.5
13	267.9	283.3	275.54	45.9
14	269.3	25.1	269.98	45.0
15	248.6	183.2	253.54	42.2
21	270.5	54.5	271.97	45.3
22	277.3	123.9	280.64	46.8
23	191.2	−18.6	190.70	31.8
24	257.3	−24.1	256.65	42.8
25	203.6	−32.2	202.73	33.8
31	192.3	205.3	197.84	33.0
32	250.1	368.9	260.05	43.6
33	234.0	−88.4	231.62	38.6
34	265.1	190.7	270.24	45.0
35	265.4	−274.0	258.01	43.0
41	261.1	−251.1	254.33	42.4
42	227.4	−0.8	227.38	37.9
43	255.3	−124.7	251.94	42.0
44	254.6	−52.6	253.18	42.2
45	265.2	−204.8	259.68	43.3
51	248.8	73.8	250.79	41.8
52	279.7	−407.7	268.70	44.8
53	250.1	−158.5	245.82	41.0
54	248.0	164.0	252.42	42.1
55	245.8	230.4	252.01	42.0
Totals	6245.2	0	6245.2	

TABLE 9.—AVAILABLE AND RECOMMENDED SQUARE LATTICE DESIGNS FOR DIFFERENT NUMBERS OF VARIETIES

Number of varieties	Number of replications										
	2	3	4	5	6	7	8	9	10	11	12
9	S	T	B* SR		SR TR*		SR BR*	TR	SR		SR TR*
											BR*
16	S	T	Q* SR	B	SR TR*		SR QR*	TR	SR BR*		SR TR QR*
25	S	T	Q* SR	P5	B* SR		SR QR*	TR	P5R* SR		SR TR QR BR*
36	S	T	SR		SR TR*		SR	TR	SR		SR TR*
49	S	T	Q* SR	P5	P6* SR TR	P7	B* SR QR	TR	SR P5R*		SR TR QR*
64	S	T	Q* SR	P5	P6* SR TR	P7	P8 SR QR*	B* TR	SR P5R*		SR TR QR P6R*
81	S	T	Q* SR	P5	P6* SR TR	P7	P8 SR QR*	P9 TR*	B* SR P5R		SR TR QR P6R*
100	S	T	SR		TR		SR	TR	SR		SR TR*
✓ 121	S	T	Q* SR	P5	P6* SR TR	P7	P8 SR QR*	P9 TR*	P10 SR P5R*	P11	B* SR TR P6R
144	S	T	Q SR		SR TR		SR QR	TR	SR		SR TR QR
169	S	T	Q* SR	P5	P6* SR TR	P7	P8 SR QR*	P9 TR*	P10 SR P5R*	P11	P11 SR TR QR* P6R

KEY TO SYMBOLS—

S Simple Lattice

T Triple Lattice

Q Quadruple Lattice

P5 Quintuple Lattice

P6, etc. Lattice of higher order than Quintuple

SR Simple Lattice Repeated

TR Triple Lattice Repeated

QR Quadruple Lattice Repeated

P5R etc. Quintuple Lattice Repeated, etc.

* Where more than one type is possible the type recommended is marked with an asterisk.

RECOMMENDED TYPES OF SQUARE LATTICE DESIGNS

Table 9 gives the possible types of square lattice designs for numbers of varieties from 9 to 169 and numbers of replicates from 2 to 12. When more than one type can be used with a given number of replicates, the one recommended is marked with an asterisk. This table can be used as follows. An experimenter wishes to test 49 varieties and decides that 6 is the maximum number of replicates that can be carried. The table gives 3 types of designs that are possible and the one marked with an asterisk is P6. This means a type in which there are 6 orthogonal groups, a different group for each replicate. It should be borne in mind in selecting these types that the differences between them are often inconsequential. Thus with 49 varieties the triple lattice repeated would be preferred by some because there would be a little less work involved in the analysis. It has been assumed in making up Table 9 that it is feasible to use partially balanced square lattice experiments up to 6 replications without repetition. Beyond that it is deemed advisable to repeat a lattice of a simpler type in order to obtain the required number of replications.

SUMMARY

1. The fundamental characteristics of square lattice designs are discussed and a generalized method of analysis presented for all such designs.

2. A table is presented showing the possible types of square lattice designs within a useful range of numbers of varieties and replicates and certain recommendations are made.

ACKNOWLEDGMENT

The author wishes to thank Professor W. G. Cochran for a critical reading of this manuscript and for making many valuable suggestions.

REFERENCES

1. FISHER, R. A. and F. YATES. Statistical tables for biological, agricultural, and medical research. Oliver and Boyd. Edinburgh, 1938.
2. YATES, F. A new method of arranging variety trials involving a large number of varieties. *J. Agric. Sci.* 26 : 424-455. 1936.
3. YATES, F. Incomplete randomized blocks. *Ann. Eugen.* 7 : 121-140. 1936.
4. YATES, F. A further note on the arrangement of variety trials: Quasi-Latin squares. *Ann. Eugen.* 7 : 319-332. 1937.
5. YATES, F. The recovery of inter-block information in variety trials arranged in three-dimensional lattices. *Ann. Eugen.* 9 : 153-155. 1939.
6. YATES, F. The recovery of inter-block information in balanced incomplete block designs. *Ann. Eugen.* 10 : 317-325. 1940.

ACIDITY: ITS RELATION TO BUTTER FLAVOUR¹

A. H. WHITE²

Science Service, Department of Agriculture, Ottawa

[Received for publication October 17, 1944]

In Canada, where a greater proportion of the creamery butter is manufactured during the spring and summer months and the surplus stored for periods of 3 to 9 months, it is important that the original quality of the cream and subsequent manufacturing procedures be such that the flavour quality of the butter does not undergo undue deterioration. Research work over the years has indicated that the churning acidity of the cream, and therefore the acidity of the butter serum, is one of the most important factors affecting both the initial and keeping quality of butter flavour.

The earlier investigations (10, 12, 13, 14, 16) were concerned mainly with the cream acidity at churning and the keeping quality of the butter, and the results showed that butter from sweet cream or cream of low acidity had much better keeping quality than butter from high acid cream. More recently Holm *et al.* (3) have shown that the rate of deterioration of flavour score for butter made from creams of 0.31 and 0.4% acidity was much more rapid than for butters made from creams churned at average acidities of 0.13 and 0.19%. They were able to correlate the loss of flavour score with increased oxidation of the fats in the high-acid butters, and concluded that the oxidation reaction seemed to underlie the various changes that resulted in a loss in score. Their data also indicated the relation between high acidity in the butter and the development of metallic and fishy flavours. Overman, Garrett and Ruehe (11) found that butters which had the highest initial scores and maintained flavour quality best during storage were made from fresh sweet creams with acidities of about 0.12%.

Studies (1, 2, 6, 7, 8) on the relation of the pH of the butter serum to keeping quality have also indicated the importance of acidity to butter flavours, and most investigators have recommended a pH of 6.7 to 7.2 in the butter serum for butters intended for storage. Bird (1) found that there was fairly close relation between the pH of butter serum and some of the common flavour defects of storage butter. At pH values below 6.6, metallic flavours became important, while fishy flavours commonly developed at pH values of 6.0 or lower. Hussong, Quam and Hammer (4) also have observed that fishy flavours are common at pH values of 6.0 or lower, or when these flavours developed at higher pH values, the butters usually contained relatively high copper contents. In studies of commercial Canadian butters (15) it was found that fishy flavours were usually present when the pH of the butter serum was about 6.0 or lower.

Investigations (5) on butter acidity at the Iowa Agricultural Experiment Station have indicated that even for creams with less than 0.2% acid, the flavour of the butter was improved by reducing the acidity to about 0.11% at churning.

¹Contribution No. 196 (Journal Series) from the Division of Bacteriology and Dairy Research, Science Service, Department of Agriculture, Ottawa.

²Associate in Dairy Research.

In commercial butters made from farm separated cream of varying quality, it is often difficult to attribute deterioration of flavour to any one particular factor. The present study was planned to obtain data on the effect of acidity of cream at churning on the initial and keeping quality of butter made from freshly separated sweet cream of fine flavour and from first grade farm separated cream, when other factors were the same or were carefully controlled. Data were also obtained on the relation between the titratable acidity of the cream and the pH of the butter serum, and gave some indication as to the acidity at which cream should be churned to give the best flavour.

MATERIALS AND METHODS

Fresh sweet cream from milk of the Central Experimental Farm herd was used for all churnings except for those in series 9 and 10 which were from farm separated cream obtained from a local dairy. In the present study it was aimed to have the different lots of cream in each series churned at acidities of 0.1 to 0.15, 0.2 and 0.3%. The individual churnings in each series were denoted by the letters A, B and C after the series number to indicate the churning acidity of the cream.

In series 1 and 2, a lot of about 250 pounds of cream was inoculated with 70 to 100 ml. of starter and held overnight at about 70° F. in a small stainless steel vat to develop acid. The following day the cream was neutralized to a calculated acidity of 0.3%, then pasteurized, and when cooled to about 100° to 110° F. was divided in 3 equal lots. One lot in each series was further neutralized to a calculated acidity of 0.2% and the other lot to a calculated acidity of 0.15%.

Churnings 3A, 4A and 8 were churned from freshly separated pasteurized creams of acidities of about 0.11%.

For churnings 3B, 3C, 4B, 4C, 5, 6 and 7, about 1 quart of starter was added to approximately 80 pounds of cream to develop an acidity of 0.2 or 0.3% and then pasteurized immediately the desired acidity was reached. In churnings 4C and 7, a higher acidity than was desired had developed and it was necessary to neutralize the cream.

For series 9 and 10 (churnings 9A, 9B, 9C and 10A, 10B, 10C), the farm separated cream was thoroughly mixed, divided into 3 equal lots and each lot neutralized to the desired acidity before pasteurization.

All creams were pasteurized at 170° to 172° F. for 10 minutes, cooled to 40° F. and held overnight before churning. A sodium sesquicarbonate neutralizer was used to reduce the acidity when necessary. Churnings were salted at a rate of 1.5% on the estimated butter. The butters were packed in 14-lb. spruce boxes lined with double 40-lb. parchments and placed in storage immediately at temperatures of about 12° F. and -10° F. The butters were stored within 2 weeks of manufacture and again after storage periods ranging from 127 to 203 days.

Titratable acidities and pH values were determined on the creams when fresh and at the churn, and pH values of the butter sera were made before and after storage. All pH determinations were made with a Beckman pH meter with glass electrode. Peroxide values of butter were made on the surface and interior portions of the butters using a modified iodi-

metric method in an attempt to evaluate the extent of deterioration of an oxidative nature. Copper contents were determined by the filtration method of Moir and Andrews (9).

Microbiological analyses were run on the butters when fresh using tryptone glucose extract agar for the standard plate count plus 0.5 ml. sterile skim milk and 0.5 ml. of a sterile fat-agar emulsion in each Petri dish, to obtain an estimate of the numbers of proteolytic and lipolytic colonies present. Malt extract agar acidified to a pH of $3.5 \pm$ was used for mould and yeast counts.

RESULTS

Data on the titratable acidities and pII values of the creams and the pH values of the butters before and after storage are given in Table 1 and indicate the treatment of the creams before churning.

With the exception of a few churnings in the low acid group, the data show a close agreement between the pH of the cream at the churn and the pH of the butter serum both when fresh and after storage. There was also good agreement between the pH values of the butters when fresh and after storage and for the same butters stored at different temperatures. With the equipment used, the pH values of the cream were slightly higher than for the resulting butters in the majority of churnings. In the case of the butters, the pH values after storage were slightly higher than when fresh, but in many instances the differences were negligible. With the exception of the first three churnings in the low acid group and one churning in the medium acid group, the variation in pH values between fresh and storage butters did not exceed 0.2 of one full division on the pH scale.

Creams with acidities of 0.10 to 0.15% gave pH values in the butter serum ranging from 6.43 to 6.95 after storage at 12° F. with an average value of 6.76; creams with acidities of 0.17 to 0.23 gave butters with pH values of 5.94 to 6.28 with an average pH of 6.11; while the butters from creams of 0.29 to 0.35% acid had pH values of 5.35 to 5.73 with an average pH value of 5.51.

The relation between acidity and flavour score for individual churnings is shown by the data presented in Table 2. With the exception of churning 1A, where the cream developed an off flavour which carried through the whole series of 3 churnings, all fresh butters with acidities below 0.15% had flavour scores of 39.5 to 40.5. Creams in the medium acid group gave butters which had flavour scores of 39.0, or 39.5 in the case of two churnings, with the exception of 1B. In several cases, however, the graders' remarks indicated the flavour was slightly acid or showing an indication of the metallic defect. For the high acid creams ranging from 0.29 to 0.35%, 4 of the 7 butters were second grade in flavour score when fresh and 3 were scored 39.0 points. In every instance, however, the butters were criticized for metallic or acid flavours or for showing an indication of the metallic flavour.

For the majority of the butters, there was no marked deterioration in the flavour scores after storage for 4 to 6½ months at the two temperatures used. In a few instances the flavour scores of the butter after storage were slightly higher than when graded fresh and the average score for the 7 churnings of the high acid group was slightly higher than when fresh. There was no loss of grade after storage for butters in the low acid group, but 2 churnings in the medium acid group and 1 in the high acid group lost a grade after storage.

The variation in the acidity of the same or comparable fresh sweet creams ripened by means of a lactic culture made a difference of 0.5 to 1 point between the flavour scores of individual churnings in the low acid and medium acid groups, and as much as 2 to 3 full points between the flavour scores of butters in the low and high acid groups. Similar results were obtained for butters made from mixed lots of farm separated creams (series 9 and 10) which had developed acid naturally. In other words the variation in acidity of the same cream meant a difference between a 40-score first grade butter and a second grade product in a number of comparisons.

While the surface butter was slightly lower in flavour score than the interior, there were only one or two instances in which the surface flavour of first grade butter had deteriorated sufficiently to lower the grade of the butter, and these were in the high acid groups. Only in the case of churning 10C did the graders observe a tendency towards a fishy flavour.

A summary of the data in Table 2 is given in Table 3. When fresh, the average flavour score for the low acid butters was 0.64 point higher than for the medium acid group and 1.5 points higher than for the high acid butters, while the medium acid group had an average flavour score 0.86 point higher than the high acid group. The average scores of the butters in the different groups showed approximately the same differences after storage for both the interior and surface portions.

The copper contents and the peroxide values of the butters are given in Table 4. The copper contents were quite low for all butters except 10C and well below 0.15 p.p.m., usually considered the maximum amount for good keeping quality. There was no apparent reason for the variation in the copper content of butters 10C and 10A made from the same cream.

Peroxide values were relatively low for all butters and are in line with the values reported by Holm *et al.* (3) for butters of comparable acidities and storage temperatures. It is of interest to note, however, that as the acidity of the butters increased, the average peroxide values increased slightly. The average peroxide values of the surface of the butters were also slightly higher than for the interior which coincides with the slightly lower average flavour scores of the surface of butters in the different acid groups.

There was very little difference in the scores of individual churnings or the average scores of butter in the three acid groups when held at 12° F.

or -10°F . The slight differences noted were in favour of the lower temperature and this was especially true for the churnings (series 9 and 10) made from farm separated cream. It should be mentioned, however, that much of the butter was made from cream that was of excellent quality except for the acid developed by good flavoured cultures of lactic acid bacteria.

The results of the microbiological analyses of the butters are not given in detail, as an examination of the data showed that the bacterial and total mould and yeast counts were approximately the same for butters of different acidities in the same series, and therefore would not influence the flavour scores of the butter. The standard plate counts of bacteria colonies were relatively low and ranged from 2,300 to 30,000 per ml. of butter, with all but 4 churnings having total bacteria counts of less than 15,000 per ml. Counts of proteolytic and lipolytic colonies ranged from 0 to 5,000 and 0 to 1,300, respectively, while total mould and yeast counts varied from 2 to 113 per ml.

DISCUSSION

The results obtained on these experimental butters, though limited in number, show the importance of proper control of the acidity of the cream and the pH of the butter, in order to obtain the best possible flavour scores on the finished butter. While only one churning in the high acid group showed a tendency towards a fishy flavour at the surface, the data indicated a rather definite relationship between acidity and the metallic and fishy flavour of butter. These results are in agreement with the general findings of other workers.

The flavour defect in the medium and high acid butters which was described as of a metallic nature was apparently not due to contamination with heavy metals as indicated by the copper content of butters of different acidities made from the same lot of cream, but was due to the acidity in the cream and in the resulting butter.

Under the conditions of these trials, the data indicated that the acidity of neutralized sour cream should be controlled within a range of 0.10 to 0.15 to obtain a pH in the butter serum of 6.7 to 7.2, which is generally considered advisable for salted butter intended for storage. Butters made from unneutralized sweet cream, however, may have a pH value somewhat lower than for neutralized sour cream of comparable titratable acidity without having a detrimental effect on flavour as indicated by the pH values and scores of churnings 4A and 8.

Although the values of the peroxide test, used as an indication of the oxidative changes in the fat, were relatively low for these experimental butters, the small increase in the average peroxide values as the acidity of the butters increased, suggests that acidity functions as a causative agent in oxidative changes that take place in the butterfat during storage, and which lead to flavour defects generally described as stale, storage, tallowy, metallic and fishy.

SUMMARY

The acidity of the cream, and therefore the pH of the butter serum, was found to have a definite effect on the flavour scores of the butter. As the average acidity of the cream increased from 0.11 to 0.20 or 0.31%, the average pH values of the butter serum decreased from 6.76 to 6.1 and 5.51, respectively, with a resulting loss in flavour scores of the butter of as much as 2 to 3 points between the low acid and high acid butters.

In the medium and high acid butters, the principle flavour defects noted were of a metallic, sour or acid, and, in one case, of a fishy nature.

The data indicated that the acidity of neutralized sour cream should be adjusted to 0.15% or lower to give a pH in the butter serum of 6.7 to 7.2 if the highest flavour scores are to be obtained on the butter when fresh and after storage.

ACKNOWLEDGMENTS

Grateful acknowledgment is made to Messrs. W. C. Cameron and S. R. Howe of the Dairy Products Division, Marketing Service, and to Mr. C. A. Gibson, Animal Husbandry Division, Experimental Farms Service, for assistance in scoring the butters, and to Mr. J. T. Janson, Chemistry Division, Science Service, for the copper determinations.

REFERENCES

1. BIRD, E. W. Effect of variation in churning acidity on the manufacture of butter. *Nat. Butter and Cheese Jour.* 30 : 1; 16. 1939.
2. GILMOUR, G. VAN B. The bearing of pH on the flavour of Irish Free State Butter. *J. of Dept. Agr. Irish Free State.* 32 : 2; 273. 1933.
3. HOLM, G. E., P. A. WRIGHT, W. WHITE, and E. F. DEYSHER. The keeping quality of butters. *Jour. Dairy Sci.* 21 : 7. 1938.
4. HUSSONG, R. V., SIDNEY QUAM, and B. W. HAMMER. Observations on fishiness in butter. *Jour. Dairy Sci.* 27 : 1. 1944.
5. IOWA AGR. EXP. STA. Annual Reports 1941-42-43.
6. KRETCHMAR, H. H. Butter: its composition and deterioration. *J. Dept. of Agr. West Australia.* 17 : 1. 1940.
7. LOFTUS-HILLS, A., L. R. SCHARP, and T. S. BELLAIRE. A study of the factors influencing the keeping quality of some Victoria salted butters in cold storage. *J. Dairy Res.* 5 : 2. 1934.
8. McDOWALL, F. H., T. W. SMITH, A. K. R. McDOWELL. Factors affecting the pH of salted butter; the relation of pH to quality of salted butter. *N.Z. Jour. of Sci. and Tech.* 19 : 6. 1937.
9. MOIR, G. W. and E. D. ANDREWS. Methods for estimating the iron and copper contents of butter. *N.Z. Jour. Sci. and Tech.* 21 : 5A. 1940.
10. MORTENSEN, M. Influence of acidity on flavour and keeping quality of butter. *Iowa Agr. Exp. Sta. Bul.* 207. 1922.
11. OVERMAN, O. R., O. F. GARRETT, and H. A. RUEHE. Studies on the keeping quality of butter in cold storage. *Univ. of Ill. Agr. Exp. Sta. Bul.* 446. 1938.

12. PATRICK, G. F. Sweet vs. sour cream butter. Iowa Agr. Exp. Sta. Bul. 18. 1892.
13. ROGERS, L. A. and C. E. GRAY. The influence of the acidity of cream on the flavour of butter. U.S.D.A. Bur. Anim. Ind. Bul. 114. 1909.
14. ROGERS, L. A., S. C. THOMPSON, and J. R. KEITHLEY. The manufacture of butter for storage. U.S.D.A. Bur. Anim. Ind. Bul. 148. 1912.
15. WHITE, A. H. Studies of storage butters showing surface deterioration. Sci. Agr. 23 : 1. 1942.
16. WHITE, W., C. S. TRIMBLE, and H. L. WILSON. Keeping quality of butter made from cream of various acidities. U.S.D.A. Tech. Bul. 159. 1929.

TABLE 1.—TITRATABLE ACIDITIES AND PH VALUES OF CREAM AND BUTTER

Churning number	Titratable acid of cream			pH of cream	pH of butter*		
	Sweet	Before neut.	At churn.		Fresh	Held at 12° F.	Held at -10° F.
1A	0.12	0.54	0.15	6.74	6.43	6.71	6.71
2A	0.11	0.54	0.15	6.76	6.64	6.95	7.02
3A	0.11	—	0.10	7.00	6.60	6.94	6.93
4A	0.11	—	0.11	6.70	6.70	6.65	6.58
8	0.11	—	0.11	6.78	6.54	6.43	6.43
9A	—	0.32	0.09	7.05	6.88	6.82	6.92
10A	—	0.44	0.10	6.87	6.78	6.86	6.97
Ave.	0.112	—	0.116	6.84	6.65	6.76	6.78
1B	0.12	0.54	0.21	6.05	5.90	6.01	6.07
2B	0.11	0.54	0.20	6.03	5.92	6.09	6.12
3B	0.11	—	0.22	5.73	5.82	5.94	5.93
3C	0.11	—	0.17	6.28	6.15	6.28	6.41
4B	0.11	—	0.21	6.37	6.05	6.28	6.20
4C	0.11	0.54	0.23	6.29	6.00	6.10	6.12
9B	—	0.32	0.19	6.30	6.12	6.14	6.17
10B	—	0.44	0.20	6.23	6.03	6.01	6.11
Ave.	0.112	—	0.203	6.16	6.00	6.11	6.14
1C	0.12	0.54	0.30	5.57	5.34	5.54	5.57
2C	0.11	0.54	0.30	5.50	5.52	5.56	5.57
5	0.11	—	0.30	5.60	5.72	5.73	5.75
6	0.11	—	0.35	5.30	5.30	5.35	5.38
7	0.11	0.34	0.29	5.72	5.48	5.35	5.32
9C	—	0.32	0.30	5.56	5.52	5.52	5.53
10C	—	0.44	0.32	5.50	5.39	5.50	5.50
Ave.	0.112	—	0.31	5.55	5.47	5.51	5.52

* pH determinations after storage were made on a different pH meter than when fresh.

TABLE 2.—THE RELATION BETWEEN CREAM ACIDITY AND PH OF BUTTER TO FLAVOUR SCORES OF BUTTER

Churn no.	Acidity of cream at churn	pH* of butter	Fresh			After storage				Surface	
			Score	Remarks	pH*	Interior		at 12° F.		at 12° F.	
						Score	Remarks	Score	Remarks	Score	Remarks
1A	0.15	6.71	38.0	Unclean		38.5	Sl. unclean	38.0	Stale	38.5	Sl. Stale
2A	0.15	6.95	40.0	—		40.0	—	40.0	—	39.0	Very sl. woody
3A	0.10	6.94	39.5	—		40.0	—	40.0	—	40.0	—
4A	0.11	6.65	39.5	—		40.0	—	40.0	—	39.0	V. sl. unclean
8	0.11	6.43	40.5	—		40.0	—	39.5	—	39.5	V. sl. storage
9A	0.09	6.82	40.0	—		39.0	Very sl. age	40.0	—	39.0	Sl. age
10A	0.10	6.86	40.0	—		39.0	—	39.5	—	38.5	Sl. woody
Ave.	0.116	6.76	39.64			39.46		39.57		39.10	
1B	0.21	6.01	38.0	Unclean		38.5	Sl. unclean	39.0	Sl. stale	38.0	Sl. tallowy
2B	0.20	6.09	39.0	Indic. of met.		39.5	—	39.5	—	39.0	Sl. stale
3B	0.22	5.94	39.0	Not full flavour		39.0	—	39.0	—	39.0	Sl. storage
3C	0.17	6.28	39.5	—		39.5	—	39.5	—	39.0	—
4B	0.21	6.28	39.0	Very sl. acid		39.5	—	39.5	—	39.0	Sl. stale
4C	0.23	6.10	39.0	Sl. sour		38.5	Sl. metallic	39.0	Indic. sl. met.	38.5	Sl. stale, sl. unc.
9B	0.19	6.14	39.5	—		39.5	Sl. age	39.5	—	38.5	Sl. tallowy
10B	0.20	6.01	39.0	Indic. sl. met.		38.0	Sl. met., sl. acid	38.0	Sl. met., sl. acid	38.0	Sl. tallowy
Ave.	0.203	6.10	39.0			38.94		39.10		38.42	
1C	0.30	5.54	37.0	Met. and unclean		38.0	Unclean, stale	38.0	Unclean, stale	38.0	Storage
2C	0.30	5.56	37.0	Metallic, sour		38.0	Sl. met., acid	38.0	Sl. acid, sl. met.	38.0	Sl. met., storage
5	0.30	5.73	39.0	Indic. sl. met.		39.0	Liner	38.0	Sl. tallowy (deg.)	38.0	Sl. stage, degrade
6	0.35	5.35	39.0	Indic. sl. met.		38.0	Sl. met., sl. stale	38.0	Sl. stale	38.0	Sl. tallowy
7	0.29	5.35	39.0	Indic. sl. met.		39.0	Liner	38.5	Sl. tallowy	38.5	Sl. stale
9C	0.30	5.52	38.0	Sl. metallic		38.5	Storage	38.0	Tallowy	38.5	Sl. stale
10C	0.32	5.50	38.0	Sl. met., acid		37.5	Metallic, acid	38.0	Tallowy, fishy tendency	38.0	Tallowy, fishy tendency
Ave.	0.31	5.51	38.14			38.29		38.32		37.79	

* pH of butter after storage at 12° F.

TABLE 3.—SUMMARY OF CREAM AND BUTTER ACIDITIES AND FLAVOUR SCORES

No. of churnings	Average cream acidities		Ave. pH of butter*	Average flavour scores				
	Titratable	pH		Fresh	After storage at 12° F.		After storage at -10° F.	
					Interior	Surface	Interior	Surface
7	0.116	6.84	6.76	39.64	39.46	39.10	39.57	39.25
8	0.203	6.16	6.10	39.0	38.94	38.42	39.10	38.75
7	0.31	5.55	5.51	38.14	38.29	37.79	38.32	38.21

* After storage at 12° F.

TABLE 4.—COPPER CONTENTS AND PEROXIDE VALUES OF BUTTERS

Churn. no.	Cu. p.p.m.	Peroxide values*			
		Storage at 12° F.		Storage at -10°F.	
		Interior	Surface	Interior	Surface
1A	0.12	0.8	1.2	0.8	1.2
2A	0.12	0.2	0.8	0.2	0.6
3A	0.08	0.1	0.5	0.1	0.3
4A	0.10	0.0	1.3	0.5	0.7
8	0.08	0.8	0.7	0.7	1.3
9A	0.07	0.0	0.1	0.0	0.1
10A	0.09	0.1	0.7	0.1	0.4
Ave.	0.094	0.28	0.76	0.34	0.66
1B	0.09	1.2	1.3	1.2	1.1
2B	0.07	0.8	0.9	0.5	0.8
3B	0.06	0.3	0.3	0.3	0.4
3C	0.07	0.1	0.6	0.2	0.4
4B	0.08	0.7	1.0	0.6	0.7
4C	0.05	0.7	1.3	0.7	1.1
9B	0.05	0.1	0.5	0.0	0.3
10B	—	0.3	—	0.3	0.6
Ave.	0.067	0.52	0.84	0.47	0.675
1C	0.06	1.2	1.2	1.1	1.2
2C	0.09	0.0	1.0	0.7	0.8
5	0.05	0.7	1.0	—	0.9
6	0.07	0.8	1.3	1.0	1.1
7	0.03	0.7	1.0	0.9	1.0
9C	0.12	0.8	0.9	0.6	0.7
10C	0.28	1.2	—	1.0	—
Ave.	0.10	0.90	1.06	0.88	0.95

* No. ml. of .002N sodium thiosulphate per gram fat.

TOPOGRAPHY AND MINIMUM TEMPERATURE¹

W. D. ALBRIGHT² AND J. G. STOKER³

Dominion Experimental Station, Beaverlodge, Alta.

Peace River settlers hailing from many countries, provinces, and states had often remarked on the sharp differences in nightly temperatures between high and low lands. The lesson had been impressed upon them by frosted grain and scorched potato tops. In winter the differences were sometimes so marked that a traveller leaving a slough and ascending 100 feet might feel almost as though leaving a frigid for a temperate climate. However, these phenomena are not confined to the Peace. The late Major L. T. Burwash told the author that he had found much greater spreads in the Yukon.

It is a principle that in the main the atmosphere tends to become rarer and colder with elevation, the temperature falling on the average about 1° F. with each 330 feet in altitude. But more than counteracting this within certain limits of local topography is a converse principle, the tendency of cold air to settle and drain to the lower levels as water drains down hill. Meteorologists call this "inversion of temperature."

This second principle is again modified by others. Low ground near a river or lake is generally safer from summer frost than high ground not so protected. When the river or lake is frozen its basin may be exceedingly cold. The narrow valley of the Peace River is an example. It seemed advisable to obtain systematic data.

After some preliminary observations in which it was established that thermometers caged 3½ feet above ground level might sometimes register nightly minima several degrees above uncaged ones at the same level, while the latter in turn might register minima 8 or 10 degrees above uncaged ones at the ground level, observations at two extreme sites were commenced by the Dominion Experimental Substation, at Beaverlodge, in July, 1926.

SITUATION

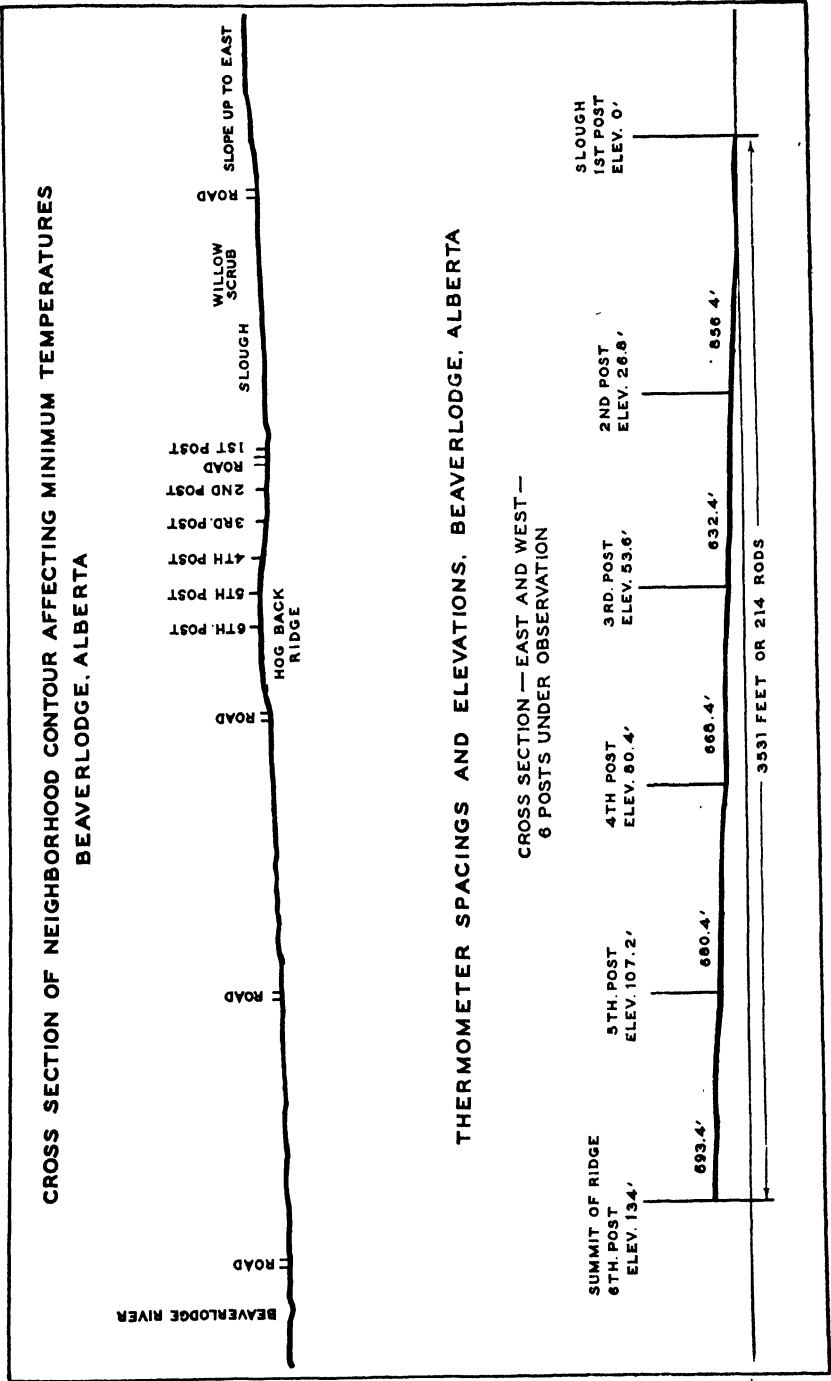
The situation was favourable for such a study. The Substation, as it then was, lay on the eastern slope of a hog's back ridge dividing two valleys that converge a mile or so to the south. The height and width of the ridge tapers pretty steadily towards that point.

The Substation land sloped sharply eastward and a little less sharply to the south. The eastward slope along the Station's southern frontage was nearly uniform, falling to a slough, which together with its adjoining scrub-covered flat occupies an area about a mile wide. The topography is such as to afford on the mile-wide flat a pool for the accumulation of cold air shed towards it from all directions but one, with a scrub-fringed outlet southeastward. The slough is locally regarded as an exceptionally frosty spot. The Substation (now a Station) lay north of a highway which crosses the slough from east to west and traverses the ridge. From the slough edge to the highest point on the ridge where it is crossed by the road the

¹ Paper read before the meeting of the Western Canadian Society of Agronomy at Saskatoon, Sask., June 22-23, 1944.

² Superintendent.

³ Weather Observer.



distance is 214 rods and the rise a remarkably gradual one of 134 feet. The ridge at this point is just over 2,500 feet above sea level. Of recent years the slough has been more or less completely drained by highway ditches and has been largely broken and cropped.

PROCEDURE

On July 1, 1926, a self-registering minimum thermometer was hung at the apex of the ridge checking against one previously placed at the slough edge. On May 1, 1927, four similar instruments were placed along the roadside between these extremes at equal successive rises of 26.8 feet, the distances being nearly uniform. All were hung $3\frac{1}{2}$ feet above ground level and were at first uncaged. Slight errors in the instruments marred some of the minor comparisons in the early years and breakages necessitated a temporary curtailment of the intermediate records in 1928. In 1929 the readings of the slough-edge thermometer between June 16 and August 24, inclusive, were discarded as inaccurate.

During the latter part of January, 1930, all six instruments were placed in louvered cages at a height of $3\frac{1}{2}$ feet. This reduced the occasional error from shaking by the wind, and lessened, though it did not altogether prevent human interference. Since April 3, 1930, the records have been interrupted but little. Occasionally a mistake would be made or a violent wind would displace the needle indicator. Any marked discrepancy in the accustomed rhythm led to the discard of the readings for such a day. A departure of 1 or 2 degrees either way was tolerated.

The readings were taken at 1.00 p.m., when the temperature was nearly always above the previous night's minimum. All instruments were occasionally compared with a reliable checking thermometer. All were situated above a grassed fence-bottom. All were on the north side of the road except the fifth from the bottom, which was placed across the road to avoid complications by trees and cultivation. The instrument at the slough-edge was designated as at post No. 1; that on the hilltop as at post No. 6. The first, second, third and sixth instruments had about equally exposed positions. Nos. 4 and 5 may have been slightly affected by artificial heat and shelter, particularly No. 4, which was southeast of the buildings and averaged a shade higher than the relationship of the other readings would lead one to expect.

Comparisons between the slough-edge and the hilltop are available from July 1, 1926, to December 31, 1942, when the readings were discontinued as a measure of wartime economy. Satisfactory comparisons of readings at six points are available from February, 1930, to December 31, 1942.

RESULTS

Since July 1, 1926, accepted comparisons between slough edge and hilltop number 5802 out of a possible 6028. On 1942 nights, which is practically one-third of the total of 5802, the slough thermometer read 10 or more degrees lower than that on the hilltop; on 649 nights, 15 or more degrees lower; on 172 nights, 20 or more degrees lower. On the other hand, on 161 nights of accepted readings the slough thermometer read 1 or more degrees less extreme than that on the hilltop.

Extreme Spreads per Annum

In every one of the 16½ years from July, 1926, to December, 1942, there has been an extreme spread of 23 degrees or more. In 6 years the extreme spread was 24 degrees; in 6 years, 25 degrees; in 2 years it was 26 degrees and in February, 1929, there was a spread of 28 degrees!

Months of Greatest Spreads

In 5 years out of 16, February registered the most extreme spread of the twelvemonth, and once February tied with December. In 4 years, March had the greatest spread; in 3 years, December; in 2 years, November, and only once did the greatest spread occur in January.

TABLE 1.—MOST EXTREME SPREADS PER MONTH FROM 1926 TO 1942, INCLUSIVE REGISTERED BY SELF-REGISTERING MINIMUM THERMOMETERS SITUATED, RESPECTIVELY AT THE FOOT AND AT THE APEX OF A HOG'S BACK RIDGE WITH AN EASTERN SLOPE 214 RODS LONG AND A RISE OF 134 FEET

Year	Most extreme spreads												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Per year
	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F
1926	—	—	—	—	—	—	13	14	15	14	18	24	24
1927	23	25	22	19	14	10	11	15	13	12	17	24	25
1928	22	23	22	16	15	12	13	14	18	15	16	23	23
1929	24	28	22	18	16	—	—	—	13	16	20	18	28
1930	22	23	25	10	13	10	14	14	14	15	21	16	25
1931	20	15	18	13	14	15	14	17	18	16	24	25	25
1932	23	20	24	13	15	13	13	16	18	12	23	22	24
1933	21	19	24	14	9	12	13	15	16	13	18	21	24
1934	26	21	19	15	14	11	12	13	12	11	18	22	26
1935	21	26	24	21	13	12	9	10	16	16	23	19	26
1936	16	23	19	13	17	15	12	14	17	14	21	24	24
1937	21	24	19	21	13	17	16	15	17	14	16	17	24
1938	22	21	14	14	15	13	15	14	13	16	18	25	25
1939	22	20	23	17	11	11	19	15	11	17	13	19	23
1940	21	22	19	11	13	10	10	14	17	16	25	24	25
1941	20	24	22	15	12	11	17	9	9	17	18	22	24
1942	18	16	17	11	12	13	16	15	16	17	25	17	25

Average Monthly Spreads

In a 13-year comparison of mean monthly spreads between hilltop and slough thermometers the widest divergence was 9.26 degrees in February, followed by 8.62 in December, 8.59 in January, 7.85 in March, 7.15 in August and 7.02 in November. June, a month of long days, had the narrowest average spread of 4.97 degrees, followed by April with 5.04; May with 5.15; October with 6.18; September with 6.47; and July with 6.48. For 13 years the average of the monthly means was 6.90 degrees. Thus while the tendency is for the colder months to show the greater spreads such is not invariably the case; nor is the converse unfailingly true of the summer months.

TABLE 3.—COMPARING 13 AVERAGE YEARLY MEANS (1930-1942) OF MINIMUM TEMPERATURES REGISTERED BY CAGED SELF-REGISTERING MINIMUM THERMOMETERS PLACED AT EQUAL SUCCESSIVE RISES ON A GRADUAL EASTERN SLOPE WITH A TOTAL ASCENT OF 134 FEET IN 214 RODS

Year	No. I		No. II		No. III		No. IV		No. V		No. VI		Spread between highest yearly mean and lowest yearly mean of I and VI
	Slough temp. yearly mean	° F.	Temp. yearly mean	Degrees above (+) below (-) No. I	Temp. yearly mean	Degrees above (+) below (-) No. II	Temp. yearly mean	Degrees above (+) below (-) No. III	Temp. yearly mean	Degrees above (+) below (-) No. IV	Temp. yearly mean	Degrees above (+) below (-) No. V	
1930	*24.44	° F.	*27.24	° F.	*28.91	° F.	*30.04	° F.	*30.35	° F.	*30.96	° F.	° F.
1931	21.37		24.74	2.80	26.51	1.67	27.89	1.13	28.33	0.31	28.98	0.61	6.52
1932	16.18		19.39	3.37	20.91	1.77	22.25	1.38	22.70	0.44	23.70	0.65	7.61
1933	14.39		17.20	3.21	18.41	1.52	19.81	1.34	20.44	0.45	21.07	1.00	7.52
1934	21.73		24.16	2.81	25.49	1.21	26.78	1.40	27.21	0.63	27.77	0.63	6.68
1935	17.98		20.95	2.43	22.31	1.33	23.88	1.29	24.15	0.43	24.81	0.56	6.04
1936	17.39		20.16	2.94	22.31	1.39	23.88	1.57	24.15	0.27	24.81	0.66	6.83
1937	17.65		20.71	2.77	21.72	1.56	23.07	1.35	23.67	0.60	24.11	0.44	6.72
1938	21.36		23.79	3.06	22.17	1.46	23.66	1.49	24.45	0.79	24.85	0.40	7.20
1939	21.30		24.03	2.43	25.25	1.46	26.84	1.59	27.80	0.06	28.21	0.41	6.85
1940	19.33		22.28	2.73	25.35	1.32	26.71	1.36	27.57	0.86	27.86	0.29	6.56
1941	21.85		24.47	2.95	23.94	1.66	25.43	1.49	26.41	0.98	26.83	0.42	7.50
1942	21.51		24.04	2.62	26.00	1.53	27.37	1.37	28.25	0.88	28.51	0.26	6.66
				2.53	25.55	1.51	27.15	1.60	27.82	0.67	28.30	0.48	6.79
Average	19.73		22.55	2.82	24.04	1.49	25.45	1.41	26.09	0.64	26.61	0.52	6.88

* Average of 11 months, February 1 to December 31.
Average spread calculated horizontally.

Spreads Decrease Towards the Top

The tendency is for the spreads to decrease as one ascends the slope. Thus in the course of 13 years, 1930 to 1942, inclusive, the second post has averaged 2.82 degrees less extreme than post No. 1, situated at the slough edge. The third post is 1.49 degrees milder than the second; the fourth, 1.41 degrees milder than the third; the fifth, 0.64 degrees milder than the fourth, and the sixth, 0.52 degrees milder than the fifth. The spread between posts 1 and 6 figures out to be 6.88 degrees (which differs by two one-hundredths from the figures arrived at where monthly spreads are averaged.)

Several factors may be suggested to explain the decrease in spreads towards the top. The cold air builds up from the bottom towards the ceiling of the inverted temperature, the cold being most intense at the bottom. The basin widens upwards and a given volume of cold, so to speak, may depress the narrower horizon of air by more degrees than it would affect the wider horizon above. In other words, a given volume of cold air will fill a narrow basin fuller than it would fill a wide one.

Frost-free Periods Hilltop and Slough

The practical importance of the study is emphasized by a comparison of frost-free periods at the slough edge and hilltop for 11 years, 1932 to 1942, inclusive. The frost-free seasons at the hilltop (32° being taken as frost) ranged from 66 days in 1935 to 129 days in 1940, averaging 106. At the slough there was frost every 10 days in 1933, and the longest frost-free period was 76 days, in 1941, the 11-year average being only 32 days. Thus the frost-free period at the hilltop averaged *more than three times as long as at the slough*. At the slough frost occurs in every month of the

TABLE 4.—LONG-TIME RECORD OF LAST SPRING AND FIRST AUTUMN FROSTS AT SLOUGH AND ON HILLTOP, 32° F. BEING TAKEN AS FROST

	Hilltop			Slough		
	Last frost in spring	First frost in fall	Frost-free season dy.	Last frost in spring	First frost in fall	Frost-free season dy.
1932	June 18	Sept. 12	85	Aug. 6	Aug. 31	24
1933	June 11	Sept. 4	84	Frost recorded every ten days		
1934	May 22	Sept. 12	112	July 19	Aug. 1	12
1935	June 8	Aug. 14	66	July 4	Aug. 14	40
1936	May 12	Sept. 10	120	June 13	July 12	28
1937	May 28	Sept. 21	115	July 11	July 27	15
1938	June 6	Sept. 29	114	June 9	July 31	51
1939	May 10	Sept. 13	125	July 13	Aug. 16	33
1940	May 28	Oct. 5	129	June 29	Aug. 4	35
1941	May 26	Aug. 30	95	June 14	Aug. 30	76
1942	May 15	Sept. 14	121	June 26	July 26	29
	Average		106	Average		32

N.B.—In computing the number of frost-free nights between, it is to be borne in mind that if the last spring frost occurs on, say, June 9, there will be 22 June nights free of frost while if the first fall frost occurs August 31, there will be only 29 August nights free of frost the reading of morning of August 1 being counted as for the night of July 31.

average year; on the hilltop roses have not infrequently bloomed in October and once as late as November. In 1943 on the hillside a perfectly good windfall apple was picked up on November 12.

It should be understood that a light frost is not necessarily lethal even to tender crops and that some crops will be little if at all injured by several degrees of frost. Thus even after allowance is made for the fact that the temperature at grain level may be lower than the temperature indicated by the caged thermometer, the fact remains that the Peace River region as a whole is a much safer cropping region than this data might suggest.

DISCUSSION

During rain or snow storms there has been no difference in the readings of the respective thermometers. Once during a slow 2-day summer rain the Station's official thermometer was observed to hover around 34 to 36 degrees F., without any sign of frost at the ground level there or at the slough. In humid, cloudy weather, even without rainfall, there is little difference. Clouds check radiation and guard against inversion of temperature.

Wind, mixing the air as it does, diminishes but does not always eliminate temperature spreads. Several degrees of difference sometimes persist in winter for days with more or less air motion in progress. On one occasion a cold wave sweeping in towards sunrise of an autumn morning brought a brief touch of frost to the hilltop without any more (if indeed any whatever) at the slough basin. This, though, was very exceptional. In some years wind has been remarked as having a predominant influence in restricting spreads, while in other years it has seemed a less important factor.

While there is a tendency for the colder months to exhibit the wider spreads and the warmer months the lesser spreads this does not hold uniformly, by any means, even when long-term averages are considered, and decidedly not when individual years are considered. Other factors, such as precipitation, clouds and wind, enter into the picture. During 13 years the greatest mean spread occurred not in the coldest month of January but in February, while the least average spread occurred in June, rather than in the hottest month, July.

February, March, December, November, and January hold the honours in this order for the greatest number of extreme spreads per annum.

The greatest spread has seldom been found on the coldest nights but rather when a cold snap was relenting, the hilltop experiencing the change first, while a blanket of cold air lay in the slough. Marked spreads may also occur with the second or third night of clearing weather following a storm. The greatest recorded spread of 28 degrees occurred on February 19, 1929, when the weather was moderating after a cold spell, the respective readings being -30 and -2 . In 1932 it was observed that the year's greatest spread of 24 degrees occurred on March 15, after a fall of snow but not on an extremely cold night.

In 1935 the greatest spread, of 26 degrees, occurred not in the bitter-cold month of January but in the comparatively mild, calm month of February, on a moderate night and after a period of mild winter weather.

In 1936 the widest spread was 24 degrees on December 19, when readings were -13 and $+11$, while the second-widest spread that year was in February, when the comparative readings were -50 and -27 . It would seem that, as with the Peace climate in general, the most regular feature is irregularity.

While no maximum readings and therefore no daily means have been registered, it has often been observed in the reading of the instruments that in summer the mid-day temperature might be as high at the slough as on the hilltop and sometimes higher. In winter it was rarely higher and was not infrequently lower in the slough.

The data is not only important from a climatological point of view but has a profound ecological significance. The frost-free period at the slough averaged only 32 nights. On the hilltop it was 106 nights. In 1933 it was roughly conjectured from 3 years' comparative data that there was probably more ecological difference between the slough and the hilltop than between Beaverlodge and Lethbridge, 380 miles farther south (though 539 feet higher than the 2444 feet which represents an average of the slough and the hilltop at Beaverlodge). Whether this comparison would hold absolutely over a long term is difficult to establish with the data at hand, but it seems likely to approximate the truth. Climatologists and ecologists are warned that the situation of a given set of meteorological instruments should be carefully regarded in the interpretation of its data.

The undulating contour of the Peace River region and the air drainage afforded by its numerous deep ravines increases its adaptability to crop production, since the high land may in many instances be chosen for residences, gardens and tender crops while frost-hardy crops such as hay, greenfeed, and, to a lesser extent, oats for threshing may be raised in the frostier areas.

SUMMARY

The Beaverlodge Experimental Station is situated on the eastward slope of a ridge tapering southward, bordered on the east by a frosty horseshoe-shaped slough-basin which receives air drainage from all directions except the southeast, where it has a flat, scrub-fringed outlet. An east-west highway ascends the slope along the front of the Station premises, with a gradual rise of 134 feet in 214 rods. At the slough-edge and at the apex of the ridge, minimum self-registering thermometers placed along the roadside were read daily from July 1, 1926, to December 31, 1942, while 4 intermediate thermometers, placed at equal successive rises, were read without serious interruption by accidents from February, 1930 to December, 1942, inclusive.

Since July 1, 1926, there were 5802 days of readings accepted as trustworthy. On 172 nights (nearly 3%) the slough-edge thermometer read 20 or more degrees lower than the one on the hilltop. As much as 28 degrees difference has been recorded, and the average spread has been nearly 7 degrees Fahrenheit.

In the 13 years, 1930-42, February had the widest mean spread (9.26 degrees) of any month, and June the least (4.97 degrees). While the colder months showed the greater ruling spreads, this was not rigidly true.

Ascending the slope, the spread in readings decreased steadily with occasional exceptions, probably attributable to the influence of adjacent buildings. The average spread between 1 and 2 was 2.82 degrees; between 5 and 6, only 0.52 degrees.

Greatest spreads usually occurred when a cold snap was relenting and on the second or third clear night following a storm. Other things equal, spreads were most marked on calm, clear nights. Rain, snowstorms, clouds and humidity appeared to reduce or eliminate them. Wind reduced but seldom eliminated them.

Preliminary readings had shown that thermometers caged 3½ feet above a lawn might register nightly minima several degrees above uncaged ones at the same level, while the latter in turn might register as much as 8 or 10 degrees above uncaged ones at the ground. Subsequent data has shown that such differences coincide with sharp differences between hilltop and slough readings.

In summer the 1.00 p.m. readings appeared to average quite as high at the slough as on the hilltop and were sometimes higher. In winter, inversion of temperature might persist in some degree throughout the 24 hours, though not always.

If a caged-instrument reading of 32° F. be taken as frost, the 11-year average frost-free period at the slough was only 32 successive nights, whereas on the hilltop it averaged 106 nights, and roses have bloomed there in November. Thus between these two points a little over half a mile apart and 134 feet different in local elevation there is probably nearly as much ecological difference as between Beaverlodge and Lethbridge, 380 miles farther south.

Undulating contour in a boreal region increases adaptability by fitting the high land for residences, gardens, tender crops and seed grain, while the low land may successfully grow fodder.

The topographical situation of any given set of weather instruments should be carefully regarded in the interpretation of its data.

ACKNOWLEDGMENTS

In the preparation of this paper acknowledgment for helpful co-operation and constructive criticism is due Messrs. E. C. Stacey, M.Sc., Assistant (Agronomy) and C. H. Anderson, B.Sc., Supervisor of Illustration Stations. For suggestions and co-operation in the initiation and conduct of the experiment acknowledgment is accorded Dr. E. S. Hopkins, Acting Dominion Field Husbandman, and Dr. A. Leahey, of the Field Husbandry Division, Experimental Farms Service.

THE EFFECTS OF SUBZERO TEMPERATURES ON *HYPODERMA LINEATUM* DEVILL.¹

R. W. SALT²

Dominion Entomological Laboratory, Lethbridge, Alberta

[Received for publication October 18, 1944]

The importance of the two common North American Warble flies, *Hypoderma lineatum* DeVill. and *H. bovis* Deg., has been greatly increased in recent years. Wartime conditions have made it necessary to carry on extensive campaigns to control these pests. Serious gaps in our knowledge of their biology have hampered control and eradication measures, and it is therefore the purpose of this paper to close one gap by presenting factual data on the effects of subzero temperatures on *Hypoderma lineatum*. Similar studies dealing with *H. bovis* are not considered necessary, since the grubs of this species drop too late in the season to be in danger of freezing.

Heretofore it has been thought that warble grubs and puparia were fairly resistant to low temperatures. Bishopp *et al.* (1) reported observations on the exposure of small numbers of larvae and pupae to temperatures of 7, 9.5, 19, and 25 to 29 degrees F. Most of the material survived, and it was concluded that "Mature larvae and pupae can withstand rather low temperatures." While this was a statement of considerable importance, the evidence was sketchy, and the need of precise data remained. The need was a practical one, for in the colder areas of the insects' range stockmen were worried about the time of the first spraying of their stock. Large herds are now sprayed with a water suspension of derris and wettable sulphur under high pressure, and if the weather is cold or likely to turn cold, spraying is not so likely to be carried on. In the meantime, grubs are maturing and some may be dropping from the animals' backs. Two problems are crucial here. First, do mature grubs actually drop during cold weather or even before the danger of cold weather is past, and to what extent? Second, what temperatures can dropped grubs survive, and to what temperatures are they likely to be subjected? Only the second of these problems is discussed in detail here, but a few observations are presented which bear on the early dropping of grubs.

MATERIAL AND METHODS

Practically all of the mature grubs and puparia used in these studies were obtained from the Livestock Insects Laboratory at Kamloops, B.C., through the courtesy of J. D. Gregson and G. P. Holland; the remainder were obtained at Lethbridge, Alberta. Larvae were kept on ice for the short period before they were frozen; puparia were kept at prevailing outside temperatures and were frozen at ages of 1 to 23 days. All larvae and puparia were frozen in the same thermocouple holder, which was constructed of rubber and glass (Salt (2)). A copper-constantan thermocouple, and a sensitive galvanometer allowed continuous reading of the temperature to an accuracy of 0.1° C. or better. The freezing chamber was kept at a constant temperature of -30° C. throughout the experiments. The rate of cooling of all specimens was therefore the same, being about 2.5° per

¹ Contribution No. 2329, Division of Entomology, Science Service, Department of Agriculture, Ottawa, Canada.

² Junior Entomologist.

minute at 0° C.; 1.0° per minute at -13° C.; 0.5° per minute at -20° C.; and 0.25° per minute at -24° C. Larvae and puparia frozen in a wet condition, to test the effects of contact moisture, were either dipped into water and the excess shaken off, or soaked between layers of damp cellulose for several hours.

RESULTS

Although the number of larvae and puparia used was fairly small, the results of the individual freezings were sufficiently consistent to give reliable data. Specimens were frozen both dry and wet, the latter to determine whether or not contact moisture would seed or inoculate the tissues and thereby lessen undercooling. Table 1 summarizes the results for 19 mature, normally-dropped, active larvae.

TABLE 1.—UNDERCOOLING POINTS FOR *Hypoderma lineata* LARVAE

Dry		Wet	
No. 5	-24.7° C.	No. 7	-24.4° C.
14	-24.7	9	-17.7
17	-24.7	10	-24.4
18	-23.9	11	-24.0
19	-25.2	12	-23.0
20	-22.7	13	-24.0
21	-19.8	15	-25.0
22	-21.1	16	-25.7
		23	-23.0
		24	-23.2
		25	-21.9
Mean	-23.4 ± 2.0° C.	Mean	-23.3 ± 2.1° C.

Combined Mean 23.3 ± 2.0° C.

Contact moisture had no effect on undercooling of the larvae. All larvae died on being frozen, even if removed from the freezer within a few seconds after the rebound started. The lethal temperature range of dropped larvae, whether wet or dry, is therefore the undercooling range, as represented by Table 1.

The corresponding experiments with puparia gave similar results. Age of the puparia, however, was taken into consideration. Each specimen, also, was carefully opened after freezing to determine its stage of development and to see if the contained larva or pupa had been alive (in all probability) before freezing. Table 2 summarizes the data on puparia.

TABLE 2.—UNDERCOOLING POINTS OF *Hypoderma lineata* PUPARIA

Larval Age 1-2 days	Pupating Age 4-5 days	Pupal Age 20-23 days
No. 1 dry -24.0° C.	No. 7 dry -20.1° C.	No. 9 dry -24.8° C.
4 dry -23.7	8 dry -19.9	10 wet -24.4
5 dry -22.2		11 wet -23.9
		12 wet -25.2
		13 dry -24.9
		14 dry -24.6
		16 wet -25.0

Combined Mean 23.6 ± 1.8° C.

Again contact moisture had no effect on undercooling, so it may be ruled out as a factor with this species. The undercooling range is practically the same as for the larvae, but less undercooling is noted in the two specimens which were in the act of pupating. Freezing was fatal to the puparia, as it was to the larvae.

Tables 1 and 2 show how low the temperature must drop before the larvae and pupae freeze and die. What temperatures are they likely to encounter in nature? The answer of course varies with the locality. A series of temperature readings was made in the Lethbridge district from February 15 to March 31, 1944. Readings were taken with a portable thermocouple-potentiometer and a copper-constantan thermocouple especially adapted for penetrating soil, manure, straw, etc., where these materials were not packed too hard. Although the pertinent temperatures were those on the surface or just under, readings were made to depths as great as 10 inches in the straw and manure of feed-lots, and down to hard material in other locations. A series of readings was taken during and soon after cold spells, and included outside locations where grubs were likely to drop, e.g., pasture, corrals and feed-lots.

In feed-lots, where straw and manure are deep, temperatures did not drop below freezing except on the surface. On the other hand, there was no danger of overheating if larvae burrowed down into this relatively soft material. In corrals, temperatures varied according to the hardness of the soil, which in turn was tied up with the amount of straw and manure present. The weather was relatively open throughout the entire period, with no snow sufficient to cover the ground except from February 28 to March 7. Snow was of little value as cover in corrals and feed-lots, as it soon was packed down and mixed with straw and manure. Much of it was melted by manure and by animals lying down on it. In open pasture, however, snow may be of considerable value as an insulator against low temperatures.

The results of this series of temperature readings, along with minimum and mean air temperatures, snow cover and the undercooling range, are shown in Figure 1. The readings are shown beneath the snow-cover figures, and represent the range of temperature readings from soil surface to a depth of 1 inch, and from snow surface to soil surface. All temperatures in the figure are on the more familiar Fahrenheit scale. The lowest temperature recorded was 8.6° F. (−13° C.) at a point $\frac{1}{4}$ inch above the soil surface, which had a fine semi-covering of snow. This reading was taken in pasture; in corrals and a feed-lot nearby the temperatures were higher.

In the vicinity of Lethbridge, during the crucial period from February 15 to March 31, 1944, warble grubs and puparia were in little danger of freezing. Although the leeway may not seem great, it is considered sufficient, especially in view of the lack of protective snow cover this year. In addition, very few individuals would freeze at 0° F., the mean undercooling point being 10 degrees lower.

The problem remains, however, to find the extent to which grubs are dropped before cold weather is past. The observations presented here are admittedly meagre, but indicate that the majority, if not all, of the earliest

dropped grubs are immature. Stockmen and technical men alike have noticed that very early in the season (February and early March in southern Alberta), white larvae, apparently full-grown, are often found stuck to the hair of infested stock or protruding partly from the emergence hole, encased in a considerable amount of pus. Usually these immature forms are dead

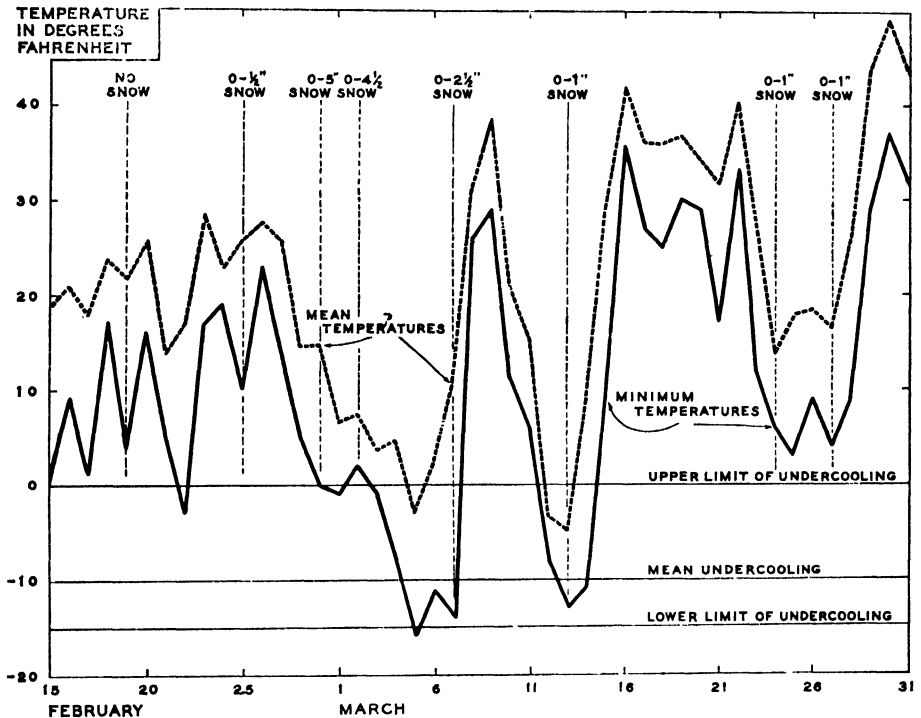


FIGURE 1. Minimum temperatures, snow cover, and undercooling range.

when found, but several living specimens were taken to the laboratory and kept to see if they would mature. All of them died within a day or two. Four others were frozen soon after removal from the backs of animals where each was found stuck in the hair. Their undercooling points were -9.8 , -10.5 , -14.6 and -5.7°C . These temperatures are dangerously high, but in view of the facts that the larvae was fastened securely to the hair, were immature, and seemed unable to mature, the danger of freezing is probably unimportant.

Fully mature grubs have not been observed by the author dropping before the danger of cold weather is past, but this may easily be the result of chance, as mature grubs are rarely seen emerging in any case. On the other hand, the white immature larvae that get stuck in the hair are readily seen. Finding an empty cyst may therefore mean the emergence of either a mature grub or an immature grub.

CONCLUSIONS

In southern Alberta there is little chance that early dropped warble grubs will be frozen and killed. To the stockmen this means that early spraying may be necessary. However, there are indications that many, if not all, of the early dropped grubs are immature forms, and that these are incapable of maturing. Further study of this aspect of the problem is of urgent practical importance.

REFERENCES

1. BISHOPP, F. C., E. W. LAAKE, H. M. BRUNDRETT and R. W. WELLS. The cattlegrubs or ox warbles, their biologies and suggestions for their control. U.S.D.A. Dept. Bul. 1369. 1926.
2. SALT, R. W. Studies on the freezing process in insects. Minn. Agr. Expt. Sta. Tech. Bul. 116. 1936.

BOOK REVIEW

FOOD ENOUGH. John D. Black, The Jaques Cattel Press, Lancaster, Penn. 1943. 269. pages. \$2.50.

Action in the Pacific Area in 1942 brought the food problem into bold relief. A situation that had been changing gradually for a year or two became a matter of serious concern. Food made the headlines and a good deal was written on the subject—some of it critical. In the United States acute shortages were predicted and the policies of the Department of Agriculture were subjected to criticism. Dr. Black, Professor of Agricultural Economics at Harvard takes his cue—and his statistics—from the United States Department of Agriculture, and in the words of his publisher, lays “a reassuring hand upon our troubled brows to clarify our thoughts in regard to the entire production picture.”

Food Enough is a book for both the layman and those who want their information buttressed by facts and figures. It is written in popular style but contains as much factual and statistical data as many texts designed for those with an analytical and scientific bent. Beginning with the food situation in general, with the needs of the armed forces, war workers and other civilians, it then proceeds to deal with Allied and enemy food supplies, with manpower and machines, with rationing shifts, in consumption, production possibilities, relief requirements and the food situation after the war. These matters are treated under twenty-one separate chapter headings.

Included in the chapters on the feeding of the armed forces and war workers are some interesting statements on nutritional requirements and the effect of organized effort to improve dietary standards. The chapter on civilian consumption reveals that though but three-quarters of the food produced is now available for civilians, no general reduction in civilian consumption has taken place. The reason of course is a greatly increased output.

Thirty-two countries draw supplies from the United States under Lend-Lease Arrangements but the major part of lend-lease transfers has gone to Great Britain and Russia. Cash sales to lend-lease countries to January 1, 1943 were greater than lend-lease exports. In the first year 47% of lend-lease shipments were food but since then the proportion has dropped to 20%.

Quoting the Office of Foreign Agricultural Relations, United States Department of Agriculture, Dr. Black indicates that the food supplies of Continental Europe in March 1943 were 15% below pre-war. The greatest reductions are thought to have occurred in swine and poultry production. The production of cereals, potatoes and other vegetables has been increased to offset meat shortages. German consumption in terms of calories, probably the highest in enemy or occupied countries, is estimated at 85 to 90% of pre-war, while Greece, at the other extreme, dependent to a large extent upon imported food, has experienced acute shortages.

In this book Dr. Black has capitalized on current interest in the food situation but he has done much more than deal with food as an article of consumption. His treatment of the subject extends from production problems to nutritional standards, and from pre-war programs to post-war planning.

Among the various matters dealt with, the discussion of prices will probably be among the most interesting to Canadian readers. While the author does not deal extensively with pre-war price policies he does refer to them. And he discusses the price policies of the war period somewhat more extensively and critically. In his concluding chapter dealing with Food After the War he makes a statement on this matter that will be of particular interest to Canadian farmers in view of the price support legislation already enacted in this country. Dealing with United States experiences, Dr. Black states:—

“If we have learned nothing from our attempts to help agriculture since 1933, we shall proceed at once to put bottoms under prices of farm products and to move the ‘surpluses’ into the ‘ever normal granary’; and to keep that granary from getting over full we shall establish ‘marketing quotas’ for all non-perishable products. And then we shall sit and wait for industry to get going again.

“But if we have learned wisdom from our experiences, we shall not look at the declining prices of foods but at their declining consumption, and we shall set about developing an efficient organization and procedure for moving enough of all foods into consumption to restore food prices to a working level.”

J. F. BOOTH.

FRAMEWORKING FRUIT TREES¹

J. J. WOODS² AND E. R. HALL³

Dominion Experimental Station, Saanichton, B.C.

Frameworking of fruit trees is a relatively recent term to describe a comparatively new way of top grafting, new chiefly in the result rather than the detail of procedure in uniting scion and stock wood. The ordinary method of top grafting is well known and requires no description. Frameworking requires that practically the whole tree with limbs and branches down to one inch in diameter be refurnished with scion wood. This method of grafting is, however, applicable chiefly to trees which have reached full bearing. From the available literature reviewed by the authors it appears that the method was first devised by Messrs. F. and W. A. G. Walker of Lalla, Tasmania. The most extensive account of frameworking that has been reviewed is an article by Garner and Walker (1). In this publication the various details of procedure are discussed and the four methods of frameworking, stub grafting, side grafting, inverted L bark grafting, and awl grafting, are fully described, together with such matters as application of methods, costs and returns and materials used. Upshall (2) describes the frameworking method in a recent publication on orchard grafting. The purpose of this paper is to describe briefly the procedure used and the results obtained at the Dominion Experimental Station, Saanichton, B.C.

MATERIALS

The bulk of the grafting work done to date has been on mature pear trees of the Bosc, Dr. Jules Guyot, and Boussock varieties using Bartlett scions. The grafting has been done in early spring when buds have commenced to swell and show green but prior to opening of blossoms. Long scions with 7 to 9 buds have been used. Less extensive trials have involved Amanlis on Dr. Jules Guyot, and the Bachelier pear on stock wood of the Chinese variety Yak, which previously had been top grafted on Dr. Jules Guyot growing on a nursery root stock. Other preliminary trials have been made with apples and plums.

RESULTS

For a variety of reasons relatively little success has attended apple and plum frameworking but with apples there has been indication that satisfactory results can be expected, though it is doubtful if the frameworked tree will come into as good production the first year as in the case of pears. A considerable number of L side grafts have been made and

¹ Paper read before the Horticultural Group at the Annual Meeting of the Canadian Society of Technical Agriculturists at Toronto, Ontario, June 26 to 29, 1944, and revised to include yield data for the year 1944.

² Superintendent.

³ Assistant Superintendent.

satisfactory union has been obtained. A 28-year-old Duchess tree worked over to Merlin in 1943 showed effective union with 80% of the scion wood but there was very little fruit in 1944.

Limited trials with plums have not given as satisfactory results as with pears. A Sugar Prune, partly frameworked to Peach Plum in 1942 resulted in only 50% union of scion and stock. On the same tree using Mallard scion wood, results were a failure. The branch on which Mallard was worked lacked vigour. In 1944 scion wood of Michelson and Mallard worked on a vigorous tree of the Shropshire Damson variety has proved for practical purposes a failure both in regard to terminal bark grafts and L



FIGURE 1. Photographed March 30, 1940, immediately after frameworking. Note long scions for both side and end grafts. Tree 2 in Table 1.

side grafts. Over a long period of years a number of plum trees have at least in part been top grafted to other varieties with a considerable degree of success. Up to the present any recommendations as to results with apples and plums must be left in abeyance. Especially with plums, incompatibility of stock and scion may be an important factor. In all frameworking it is, however, necessary to use only trees in a vigorous state of growth.

The first work with pear trees undertaken at this Station was commenced in 1939 by the junior author when a 25-year-old Dr. Jules Guyot pear tree was worked over to Bartlett. The method adopted at this time and followed since was to cut off all wood less than one-half inch in diameter, leaving nothing but a skeleton (See Figure 1). The L bark graft was adopted



FIGURE 2. Frameworked in 1940. Photographed in Feb. 1941. Tree 3 in Table 1.

for all side grafts and the ordinary bark graft for stubs of sufficient size. In the case of small stubs cleft grafting has been used, but when sufficient skeleton branches of large enough size for bark grafting are available the cleft method is not recommended. In 1940 another Dr. Jules Guyot was worked over, also a 25-year-old Bosc. In 1941 a third Dr. Jules was frameworked and in 1942 eight 28-year-old Boussock trees were frameworked and an equal number were top worked by standard methods. The 16 trees were in a single row and trees were alternated for the two grafting methods.



FIGURE 3. Frameworked in March, 1939. Photographed in Aug. 1940. Tree 1 in Table 1.

Table 1 gives results obtained from trees frameworked at this station, with yields prior to and subsequent to grafting.

TABLE 1.—TOTAL YIELD OF FRUIT FROM FRAMEWORKED PEAR TREES WITH BARTLETT SCIONS

Tree	Variety	No. of scions	Yield							
			1937	1938	1939	1940	1941	1942	1943	1944
			lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
1	Dr. Jules Guyot	125	137	9	Frame-worked	98	208	189	21	141
2	Bosc	112	271	356	157	Frame-worked	192	221	Out	Out
3	Dr. Jules Guyot	125	9	263	174	Frame-worked	162	258	4	243
4	Dr. Jules Guyot	106	15	229	171	176	Frame-worked	124	155	141
5	Boussock	132	—	365	136	474	48	Frame-worked	137	271

This table shows that one year after frameworking the trees came into commercial production. It further shows that after the second year of production, particularly in trees 1 and 3, that alternate bearing had again become established. Due to the position in which it was growing, tree 2 had to be taken out in the fall of 1942. Heavy fruiting the year after grafting has caused numerous branches to break but in no instance either from wind or weight of fruit have scions been broken out at the point of union.

The 8 Boussock trees grafted in 1942 had a lot of rough, tough old bark which is characteristic of mature trees of this variety. It appreciably increased the labour in making both the L and bark grafts. The number of trees involved in the trial made it possible to obtain more reliable data than had previously been obtained as to costs of frameworking and also permitted comparisons to top working. Table 2 gives the results obtained.

TABLE 2.—COMPARATIVE RESULTS OF FRAMEWORKING AND TOP WORKING PEAR TREES, 1942

	Top worked by usual method	Frameworked
Kind of stock	Boussock	Boussock
Kind of scion	Bartlett	Bartlett
Number of trees grafted	8	8
Date of grafting	April 9-10	April 11-17
Total number of scions set	171	1060
Total hours required in grafting	28	90
Number of scions alive in June	171	950
Mortality in scions	0 0%	10 3%
Time required to remove branches	—	16 hrs.
Number of buds per scion	2-3	8-10
Time to remove suckers during 1942	0.75 hrs.	6.75 hrs.

The total cost for the 8 top worked and 8 frameworked trees was respectively \$14.20 and \$46.60. The cost in top working includes the final grafting operation in 1943. These figures are comparatively high due to the very hard bark on the Boussock variety and to the fact that a considerable amount of relatively inexperienced labour had to be used.

Table 3 presents yields and value of crop for 1943 and 1944 from frameworked and top worked Boussock trees using Bartlett scions.

TABLE 3.—PRODUCTION AND VALUE OF CROP (BARTLETT) FROM TREES GRAFTED IN APRIL, 1942

Method of grafting	Yield and grade		Value of crop	Total value of crop
	No. 1	No. 2		
	lb.	lb.	\$	\$
Top worked (8 trees)				
1943	88	0	2.64	—
1944	559	127	28.92	31.56
Frameworked (8 trees)				
1943	1098	0	32.94	—
1944	991	781	70.63	103.57

Grades as shown in Table 3 are based on size of fruit demanded for canning purposes. Size of fruit in 1943 for No. 1 grade was 2.00 inches and in 1944 the requirement for Grade 1 was 2.125 inches and 2.00 inches for Grade 2. The value of the crop is based on selling prices of \$60.00 per ton for Grade 1 in 1943 and in 1944, \$87.50 per ton for Grade 1 and \$70.00 for Grade 2. All prices are f.o.b. cannery.

In topworked trees (8 trees in 1942) grafting costs were \$14.20 for 8 trees and revenue \$31.56 to the end of 1944. In frameworked trees (8 trees in 1942) grafting costs were \$46.60 and revenue \$103.57 for the same period.

CONCLUSIONS

From frameworking experiments conducted at this Station since 1936 the following conclusions may be drawn.

1. With apples, more evidence is needed to show that the extra cost of frameworking is justifiable.

2. With plums there is needed a considerable study to determine whether incompatibility of stock and scion is the limiting factor in successful frameworking and top working.

3. With pears, highly satisfactory results have been obtained and frameworking can be recommended. There has been no evidence of any incompatibility when using four different stocks with Bartlett scions, one stock with Bachelier scions and another with Amanlis scions.

4. Only trees in a vigorous healthy state should be used for any grafting.

ACKNOWLEDGMENT

The authors extend their thanks to Mr. F. A. Maxwell, orchard foreman at this address for his keen interest and accurate records in carrying out the various grafting and harvesting operations.

REFERENCES

1. R. J. GARNER and W. F. WALKER. The frameworking of fruit trees. Imp. Bur. of Hort. and Pl. Crops. Occ. paper No. 5. 1938.
2. W. H. UPSHALL. Orchard grafting. Ont. Dept. of Agr. Bul. 439. 1944.

PROMISING NEW METHODS USED IN PROPAGATION OF HYACINTHS¹

J. H. CROSSLEY²

Dominion Experimental Station, Saanichton, B.C.

Any method that will shorten the time required to produce large sized flowering bulbs of hyacinths or that will facilitate their propagation is of special value in view of their slow natural increase. It is the purpose of this paper to describe three new or little known methods and practices that have a bearing on these points. The methods described are (1) the Saanichton system of propagation, (2) the production of hyacinth bulbs from discarded basal plates, and (3) scaling the bulbs after incubation. Reference is made to the standard system of hyacinth propagation as it relates to the contents of this paper. This is not described because it is generally well known to hyacinth propagators.

HISTORY

The Saanichton system of propagation is based on the results of experiments conducted at the Dominion Experimental Station at Saanichton, B.C. The original experiments were begun prior to 1916. Among other things demonstrated by these early experiments was that callusing freshly cut hyacinth bulbs could be achieved under moist conditions without impairing bulblet formation. Thus, the dry phase of callusing was omitted resulting in the period for callusing and that for incubation commencing simultaneously. This procedure is opposed to the generally accepted practice which stipulates that freshly cut bulbs should first be callused under dry conditions for a period of 2 to 3 weeks before they can be safely incubated under moist conditions (3), (9). Other experiments have shown that under Saanichton conditions, the dry period of callusing has an adverse effect which increases with the rise in temperature and the duration of the exposure. (8). Results from these experiments, which warrant omitting the dry callusing period under Saanichton conditions, form the basis for the system described. Additional data are needed before the Saanichton system can be widely accepted, and experimental work along these lines is being continued.

The planting of basal plates has been done by at least two other propagators. Generally, however, this means of propagation appears to have been overlooked. From the literature available there are no data on the subject.

Scaling, which is separating the scales after incubation so as to leave a piece of the parent scale attached to each bulblet, is not a usual practice. This method is not mentioned in the literature and is relatively new. On the other hand, scaling before incubation is not uncommon. In 1935, Luyten (4) described a similar method in which scaling was done before incubation. The material used in this case was *Hippeastrums*. Although scaling as outlined in this paper has not been tried by the author, it has been carried out successfully by a hyacinth propagator for several years on Vancouver Island.

¹ Paper read before the Horticultural Group at the Annual Meeting of the Canadian Society of Technical Agriculturists at Toronto, Ontario, June 26 to 29, 1944.

² Assistant.

MATERIALS AND METHODS

The Saanichton system of propagation as well as the standard method requires that there be a high degree of control of temperature and humidity during the incubation period. For this purpose there is used a specially built cabinet with thermostatic heat control (Figure 1). It is provided with a fan to equalize temperature which is held at 26.7°C . throughout the propagation period. Heat is generated by a 100-watt Mazda lamp.



FIGURE 1. Specially built cabinet used for incubating hyacinth bulbs in the Saanichton system of propagation. The scooped bulbs are placed in gallon crocks containing moist sphagnum peat moss. The crocks are sealed with wax paper to retain the moisture in the peat. A 100-watt Mazda lamp generates the heat which is distributed by an electric fan and controlled by a thermostat. The figure also shows scooped bulbs on screen trays. When this method is used, a solid bottom tray is filled with dampened sand. The sand is kept moist during the entire incubating period.

The procedure followed in the Saanichton system is similar to the standard method but with one important exception. In the Saanichton system the dry period of callusing has been omitted. Instead, the freshly cut bulbs are placed directly into moist sphagnum peat moss, or a mixture

of moist sand and peat, and incubation started immediately. To maintain the proper level of humidity the bulbs and peat are placed in a crock or container and covered with a lid consisting of a piece of wax paper held in place with an elastic band. A suitable level of moisture when using peat alone is approximately 230% on a dry weight basis. During the period of incubation the container with its contents is left in the cabinet. Incubation is completed about October or early November. By this time the bulblets have developed sufficiently for planting. For planting, the bulblets are left attached to the mother bulbs.

Bulbs measuring 16 to 20 centimeters in circumference with thick fleshy scales and no attached offsets are used for cutting. The bulbs are cut with a sharp budding knife (Figure 2). The scooping method of cutting is used in preference to scoring or coring. This is done when the bulbs are fully ripened, which is usually in July.

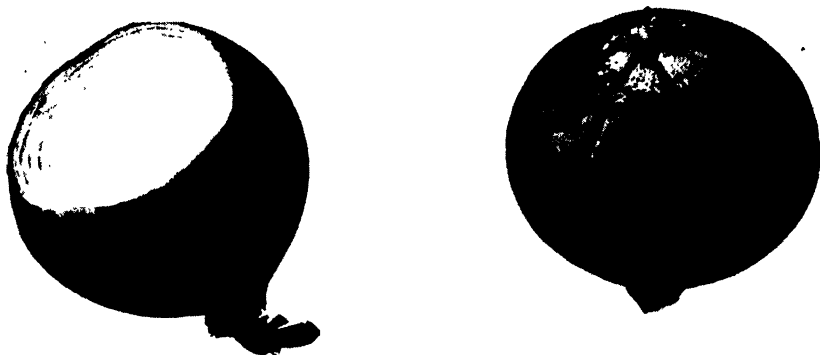


FIGURE 2. The scooping (right) and scoring method of propagating hyacinth bulbs as illustrated on onions. The former method produces a large number of small bulblets; the latter yields fewer but the average size is larger.

Fairly satisfactory substitutes for the controlled temperature cabinet have also been used. These include a glass covered cold frame and a greenhouse propagating frame where the only source of heat is the sun. Another type makes use of an oil lamp which more or less controls the temperature. Types which give the greatest temperature control are most satisfactory.

The only material required when propagating from basal plates is a container filled with moist peat as already described under the Saanichton system. The procedure followed with basal plates which are obtained from scooped bulbs is to place the plates immediately into the containers with the peat. The most suitable temperatures for the storage of the basal plates while in the peat have not been determined but the fluctuating temperatures in a greenhouse propagating frame seem satisfactory. In November the plates are planted outdoors.

The materials required when scaling scooped bulbs are large sized greenhouse flats, a quantity of rich compost, some sand and a basement or room where the temperature is between 10° and 15° C. The procedure now followed is to remove for planting each bulblet with a piece of the parent scale attached after incubation is completed. This is in contrast to the standard method in which the scooped bulbs are planted intact. The bulblets are planted in the flats which contain a lower layer of compost and an upper layer of sand. The base of the bulblet is planted so that it rests in the sand layer and just above the compost. Sand is screened over the bulblets so that the final covering is about 1½ inches deep. The flats are kept in a basement until top growth appears, after which they are transferred outdoors. This takes place usually after the New Year. The bulblets grow in the flats for one season. When they have ripened they are harvested and reset in the ground in nursery rows. (Figure 3).



FIGURE 3. Harvesting 1-year-old hyacinth bulblets raised from scooped bulbs which were scaled after incubation. Each bulblet was planted individually with a piece of attached scale removed from the scooped parent bulb. Planting was done in greenhouse flats. The flats were left in a cool basement until top growth appeared after which they were transferred outside. The above figure illustrates the method of separating the bulblets and compost after the tops had ripened off in July.

RESULTS

Results from the Saanichton system have been fairly satisfactory. The peat provided a cheap and effective means for maintaining a suitable level of humidity. It was also effective in eliminating or reducing moulds and storage rots during incubation to a point where they were relatively unimportant. For these reasons routine inspections were reduced from several to one or two resulting in a saving of time. Placing the freshly cut bulbs immediately into the moist peat eliminated the separate and additional operation of callusing under dry conditions.

Planting basal plates in November, 1942, showed that 30% of the bulbs harvested after the first season measured 8 centimeters or more in circumference. The largest bulb measured 13 centimeters and two offsets were attached. In another experiment from planting basal plates in 1943, 97% produced satisfactory plants. Of these, 52% produced flowering spikes, the majority of which had between 10 and 20 medium sized florets each.

Results from scaling indicate that a saving of one year was obtained.

DISCUSSION

The Saanichton system offers certain advantages that the standard system does not. This advantage is chiefly a saving in time as a result of: (1) the elimination of the dry callusing operation considered essential in the standard method, (2) the reduction in the number of routine inspections necessary to maintain a level of humidity in keeping with healthy storage conditions. The cheap and effective means for maintaining humidity which is provided by the peat is also an important advantage. Control of humidity is usually a problem left to the judgment of the propagator unless special apparatus is installed. Though yields from the Saanichton system have not quite equalled those recorded as average elsewhere (3, 9), evidence indicates that this may be satisfactorily overcome. Experiments along this line are continuing.

The results from planting basal plates show that this method of propagation is satisfactory from the standpoint of bulb production. Propagators are thus given another means of increasing their stocks. Compared with the scoring practice, propagation from basal plates rates as a quicker method of producing larger sized bulbs though the quantity is considerably less.

In regard to the time saved as a result of scaling bulbs after incubation this advantage is evidently the result of the optimal spacing allotted to each bulblet. Time consumed in scaling is not excessive. It is possible, however, that this may be a limiting factor where mass production is carried on. At present, scaling would appear to merit more extensive use.

SUMMARY

1. Three new methods of hyacinth propagation are described. These are: (a) the Saanichton system, (b) planting basal plates, (c) scaling scooped bulbs after incubation.

2. The Saanichton system introduces a different aspect to the commonly accepted idea that dry callusing is a prerequisite to the incubation phase of propagation. The new system omits the dry phase and in its place moist peat is substituted.

3. Advantages offered by the Saanichton system are: (a) saving in time required during propagation, (b) a cheap and effective means for maintaining humidity.

4. The propagation from basal plates which were heretofore discarded is considered a satisfactory new method of increasing hyacinth stocks.

5. Scaling of scooped bulbs after incubation indicates a saving of one year in the time required to produce large sized flowering bulbs.

ACKNOWLEDGMENT

The author is indebted to Mr. J. J. Woods, superintendent of the Dominion Experimental Station, Saanichton, and various members of the staff for reading and criticizing the manuscript of this paper.

REFERENCES

1. BAILEY, L. H. Standard Cyclopedia of Horticulture.
2. HOTTES, A. C. Practical Plant Propagation. 1927.
3. GRIFFITHS, D. The Production of Hyacinth Bulbs. U.S.D.A. Circ. 112. 1930.
4. LUYTEN, I. Vegetative propagation of Hippeastrums. Yearbook American Amaryllis Soc. 2, and Meded. Lab. Pl. Physiol. Wageningen 46. 252-60. 1935 and 1936.
5. PRIESTLY, J. H. and C. F. SWINGLE. Vegetative propagation from the standpoint of plant anatomy. Tech. Bul. 151, U.S.D.A. 1929.
6. STEVENSON, L. S. Bulbs and Bulb Bloom. Dom. Dept. Agri. Bul. 48. 1921.
7. REPORT OF THE SUPERINTENDENT. Dom. Experimental Station, Saanichton, B.C. 1942. (Unpublished).
8. REPORT OF THE SUPERINTENDENT. Dom. Experimental Station, Saanichton, B.C. 1943. (Unpublished).
9. COMMERCIAL BULB PRODUCTION. The Ministry of Agriculture and Fisheries. London. Bul. 62. 1938.

ANALYSIS OF HORTICULTURAL SOILS¹

R. GOODWIN-WILSON²

Ontario Agricultural College, Guelph, Ontario

The use of rapid methods of soil analysis was begun in the Department of Horticulture, Ontario Agricultural College in 1937 at the request of some commercial florists. At that time much publicity was being given to such methods of analysis in trade papers, perhaps causing undue optimism among growers that a "cure-all" had been discovered. This phase was followed by many disappointments, but as enough growers remained interested the work was continued.

Spurway (1) procedures were used because his extracting solution for the more readily available substances was found to be admirably suited to the high nutrient levels usually found in greenhouse soils. Records of analyses were noted as parts per million and growers were soon using the term "p.p.m." intelligently. The analyses were based on the soil extract.

Each sample of soil was tested for active (readily available) nitrogen as N in the NO₃ form, potassium as K, phosphorus as P, calcium as Ca, magnesium as Mg, sulphates as SO₄ and chlorides as Cl. Reserve tests were made for phosphorus, potassium, iron and manganese. The total soluble salts was determined by the use of a resistance machine, and pH by means of either Bromothymolblue or in the case of muck and peat soil by means of a glass electrode potentiometer.

GREENHOUSE SOILS

(a) Ornamentals

There are comparatively few persons in Ontario who grow ornamentals under glass extensively and thus it was possible to establish and maintain good contact with the industry throughout the developmental phases of the work. The growers themselves had important unsolved production problems which were readily seen by them because of the nature of their business. Good co-operation was received from the growers and in no small measure was responsible for the successful development of the project. Their records were reliable and any soil manipulation such as the addition of fertilizer was carefully done.

The general procedure in the attempt to determine suitable nutrient levels for the various crops was as follows. The grower sent in soil samples from specific crops at regular intervals during the growth of the crops. Each set of analyses was accompanied by suggested soil treatments, and visits were made regularly to study the effect on the crops of the suggested treatments. A complete history of each bench in each greenhouse was kept over a period of years. Eventually it was possible to determine by comparison from the accumulated data the approximate optimal levels of nutrients for each crop. Now nearly all of the larger greenhouse establishments make full use of quick soil analyses as part of their regular practice and many of them have established laboratory facilities of their own.

¹ Paper read at the Horticultural Group meetings of the Canadian Society of Technical Agriculturists at the Annual Meeting at Toronto, Ontario, June 26-29, 1944.

² Research Assistant, Department of Horticulture.

The chief results obtained have been control of the type of growth required for a given variety of plant at the different growing phases, important savings in the amounts of fertilizers used, the virtual elimination of toxic accumulations of nutrient materials, and it has been possible with the help of sterilization and leaching to use the same soil more or less indefinitely and thus eliminate the tedious and expensive job of frequent soil changes.

The principal crops grown were, and are, roses, carnations, chrysanthemums, and snapdragons. The nutrient levels best suited for the production of roses in Ontario were found to be very similar to those recommended by American investigators, i.e. nitrate nitrogen 20-25 p.p.m.; phosphorus 8-12 p.p.m.; potassium 20-30 p.p.m. Chrysanthemum levels were found to vary considerably with varieties. Some varieties which are slow growers, with small hard foliage, needed nitrate nitrogen levels of 10-12 p.p.m., whereas the vegetative varieties needed comparatively low nitrogen levels, ranging from trace to 5 p.p.m. Chrysanthemum requirements for phosphorus and potassium were similar to those for roses. Carnations differed from roses and chrysanthemums in that they needed a phosphorus level of at least 12-16 p.p.m. Snapdragons were found to respond best to very low nitrogen levels of trace to 3 p.p.m. of nitrate nitrogen; 8-12 p.p.m. of phosphorus and 15-20 p.p.m. potassium. Apart from the various levels of nitrogen, phosphorus, potassium, calcium, etc., the Spurway test for sulphates and chlorides has been invaluable in preventing the accumulation of these residue salts in toxic quantities.

(b) Vegetables

A survey is being made of greenhouse soils producing vegetables and the method used in an attempt to determine the approximate optimal nutrient levels is similar to that described above for ornamentals. Travel restriction has curtailed the number of districts included in the survey but 26 commercial houses are being visited regularly. It is not possible at this time to give definite data, but there are reasonably well founded indications concerning good nutrient levels for the two major crops, cucumbers and tomatoes. Nitrogen levels varied over a wide range from 5-20 p.p.m. with satisfactory results and it would appear that from 5-10 p.p.m. nitrogen is sufficient. Active phosphorus 16 p.p.m. and active potassium 30-40 p.p.m. seem to be adequate.

INTENSIVELY CULTIVATED VEGETABLE SOILS

(a) Upland

The number of vegetable growers runs to thousands, and the procedure used in an attempt to determine approximate optimal nutrient levels was of necessity somewhat different from that used in the study of greenhouse soils. It was realized, too, that the problem of outdoor crops was much more complex in that an infinite number of soil variations occur, methods of husbandry vary greatly and environmental conditions cannot be controlled as under glass. A survey was made in 1941 with the areas to be studied selected more or less at random. Thirty-four growers in eight districts were chosen, and each was visited at approximately fortnightly intervals during the growing season with the purpose of collecting soil samples and making observations on any factors other than nutrition

which might influence the yield of the crop being studied. Successive analyses from each field were characterized by either the maintenance of levels for each element or by uniform drifts. Nitrogen was the exception in that it fluctuated frequently and rather widely. The crops were graded as Good, Fair, and Poor and an attempt was made to assess the effect on the grading of such factors as drought and pests. The complete data are to be found in a bulletin (2) published in 1942. We believe that the data warrant the assumptions indicated in the following table for the crops studied. Those crops included: beets, cabbage, carrots, cauliflower, head lettuce, onions, tomatoes, asparagus, egg-plant, radish, sweet pepper, parsnips, and celery.

TABLE 1.—NUTRIENT LEVELS FOR UPLAND SOILS IN RELATION TO TRUCK CROP PRODUCTION IN SOUTHERN ONTARIO

Nitrogen in p.p.m.		Phosphorus in p.p.m.		Potassium in p.p.m.		
Average	Range	Available	Reserve	Available	Reserve	
4 +	Trace to 20	12 +	20 +	20 +	50 +	Adequate
2	Trace to 6	6	12	10	20	Marginal
		Below the above levels.				Deficient

The co-operation of the Ontario Women's Institute Branch and the members of their "Girls' Garden Brigade" made it possible to get soil samples from 682 farm gardens scattered widely over the province, and because these gardens were judged in competition it was possible to obtain information on the crop behaviour. Probably the results cover a fair cross section of the gardens producing vegetables on a non-commercial basis and a summary of the nitrogen, phosphorus, potassium and pH levels are given in the following table.

Summary of Results of Survey of Girls' Garden Brigade Soils

<i>Nitrogen</i>	54% low to very low (zero to 1 p.p.m.)	
	7% high (6 p.p.m. and up)	
<i>Phosphorus</i>	52% very low (active and reserve)	
	4% high (8 p.p.m. and up, active)	
<i>Potassium</i>	50% very low (active and reserve)	
	7% high (20 p.p.m. and up, active)	
5.5% had a pH of 6.0 or lower.		

(b) Peat and Muck

Two of the larger muck areas, Thedford Marsh and Bradford Marsh, have been under investigation for the past 4 years and the Eriau Marsh during the past year. This type of soil presents rather a peculiar problem in that the nutrient levels are considerably lower than those found on upland soils. This is especially true of the Thedford and Bradford Marshes. Despite heavy applications of fertilizer, particularly those of high potash

analysis, nutrient levels of nitrogen trace-2 p.p.m., phosphorus 2-5 p.p.m., and potassium trace-10 p.p.m., are found producing excellent crops. No explanation is offered for this phenomenon at the present time. This is not so true of the Erieau Marsh. The nutrient levels in this particular area are quite comparable to some of our upland market garden areas. This project is still under investigation and the work carried on in the Erieau Marsh is being done in co-operation with the Western Ontario Experiment Station at Ridgeway and the Department of Chemistry here.

SUMMARY

The use of rapid methods of soil analysis is now firmly established in greenhouses devoted to the production of florist crops and there is every reason to believe that it will become standard practice in greenhouses in which vegetables are grown. When sufficient cognizance is taken of factors, other than soil nutrients, which may affect vegetables grown intensively in upland soils, and when it is remembered that there are often hidden factors affecting such crops, it has been demonstrated that soil analyses are definitely useful in the production of vegetable crops.

REFERENCES

1. SPURWAY, C. H. Mich. Agr. Exp. Sta. Tech. Bul. 132 (Rev.). 1935.
2. JONES, T. H., R. GOODWIN-WILSON and J. H. L. TRUSCOTT. Ont. Dept. of Agr. Bul. 421. 1942.

SOIL NITRATES UNDER VARIOUS FERTILIZATION AND GREEN-MANURE CROPPING SYSTEMS¹

W. H. UPSHALL², O. A. BRADT³ AND J. R. VANHAARLEM⁴

Horticultural Experiment Station, Vineland Station, Ontario

A very important element in the nutrition of fruit trees is nitrogen, a deficiency of which results in poor growth and fruiting, and an excess, in susceptibility to disease and winter injury. It is becoming generally recognized that available nitrogen should be in good supply in the soil during the spring and early summer to stimulate good growth, but by July should be nearly exhausted so that growth may cease. Stoppage of growth at this time is desirable to permit the accumulation of carbohydrates necessary for good fruit colour and satisfactory wood maturity.

The maintenance of soil organic matter in orchards is causing some concern to growers. In non-sod orchards a shortening of the early-season cultivation period permits a longer season for growing green-manure crops and a consequent increase in dry matter to be incorporated with the soil. Farm manure is being added to many orchards and some growers are using straw and old hay. Little is known about the effects of these treatments on soil nitrates except that the incorporation of dry matter, itself low in nitrogen, may result in nitrogen starvation of companion or succeeding crop.

PLAN AND PROCEDURE

A comprehensive experiment on the maintenance of soil organic matter was commenced in 1936 at the Ontario Horticultural Experiment Station. Small plots on a fine sandy loam soil were planted to various annual crops commonly used as green manures in orchards. Each crop plot was divided into three sections for differential commercial fertilizer treatment: a, unfertilized; b, 400 lb. 0-12-15 fertilizer per acre per year (PK); c, same as b plus 300 lb. sulphate of ammonia per acre per year (NPK). Each section was 36 feet by 8 feet, approximately 1/150 of an acre.

Five buckwheat plots were given the following annual applications: 1, farm manure, 10 tons per acre; 2, legume hay, 3 tons per acre; 3, straw, 3 tons per acre; 4 and 5, half-rate combinations of straw with the other two materials. In dry matter 3 tons of hay and 3 tons of straw are each approximately equivalent to 10 tons of farm manure. All fertilization, both organic and inorganic, was done about the middle of May, a few days before the green-manure crop was seeded.

Each crop-fertilizer treatment was in duplicate, occurring in A and B Series. Samples for nitrate determinations were taken from the b (PK) and c (NPK) sections of certain plots in A Series only. Each soil sample was a composite of three borings or diggings in the top 6 inches of each section. Tests were made about every two weeks from mid-May to late September. Nitrates were determined immediately by the phenoldisulphonic acid method and the results were calculated as parts per million on the oven-dry weight basis.

¹ Paper read at the Horticulture Group meetings of the Canadian Society of Technical Agriculturists at the Annual Meeting at Toronto, Ontario, June 26-29, 1944.

² Chief in Research.

³ Assistant in Research.

⁴ Research Chemist.

RESULTS

The Accumulation of Soil Nitrates under a Buckwheat Green-manure Crop, as affected by Applications of Farm Manure, Straw, and Legume Hay

(a) Without added nitrogen (PK)

Legume hay alone gave the highest average nitrate readings and, except at the beginning of the season, straw alone gave the lowest readings (Figure 1). There was little difference between the manure treatment

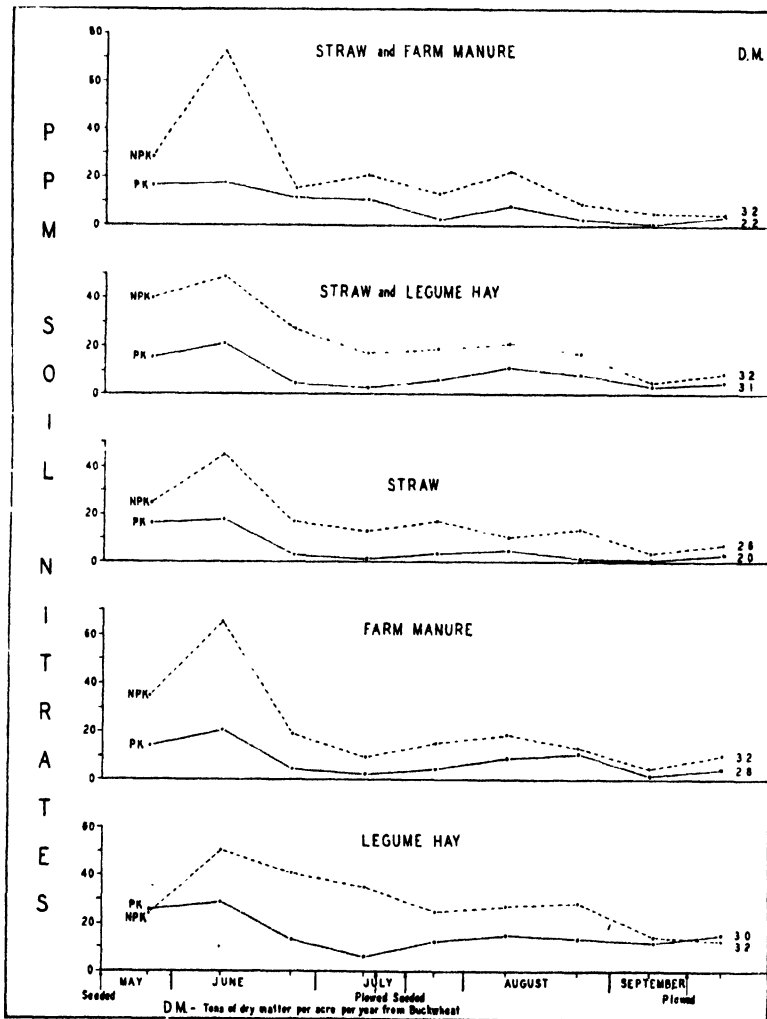


FIGURE 1. Soil Nitrates, 1937-41, under buckwheat green-manure crop, two per year, as affected by annual applications of farm manure, straw, and hay, both with and without added nitrogen.

and the straw-hay and straw-manure combinations, though the latter tended to be slightly lower in the latter part of the season. Straw, used singly, depressed the yield of buckwheat and there was only slight improvement with the straw-manure combination but the straw-hay combination

gave yields in line with legume hay, and with manure. The decomposition of the straw, a low-nitrogen material, tended to keep the soil nitrates relatively low throughout the growing season but at the beginning of the next season, soil nitrates were as high in this plot as in any of the others except the legume hay plot.

(b) With added nitrogen (NPK).

Almost without exception, the addition of 300 lb. per acre of sulphate of ammonia in mid-May increased the soil nitrates *throughout the whole season* (Figure 1), even though the greater growth of buckwheat stimulated thereby probably resulted in greater nitrogen usage. The addition of nitrogen to the straw plots increased the soil nitrates above the non-nitrogen plots of the other treatments, and yet high yields of dry matter

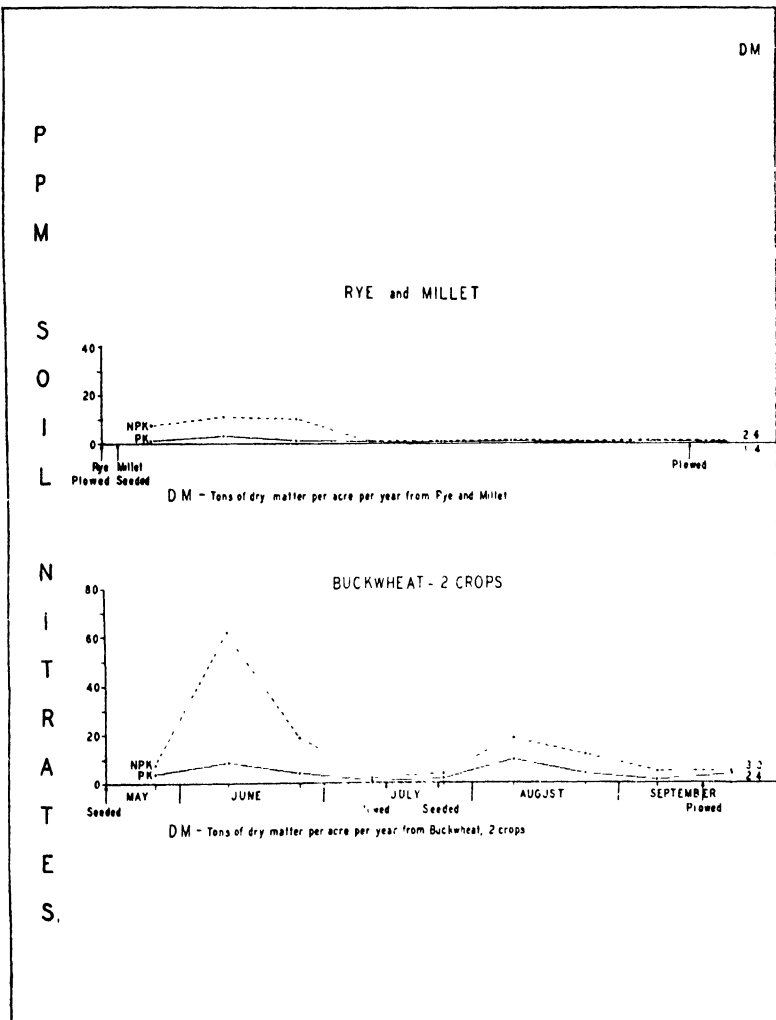


FIGURE 2. Soil nitrates, 1940-42, under buckwheat, and rye-millet green-manure crop, both with and without added nitrogen.

did not follow. There is a suggestion therefore that factors other than nitrogen limitation operate against the growth of buckwheat when straw is used by itself.

The Accumulation of Soil Nitrates under Buckwheat, and Rye-millet Green-manure Crops

The comparison is between buckwheat two crops per year, and the rye-millet combination (Figure 2). Rye was sown in the fall, plowed under in the spring before heading, and millet was planted a few days later. While buckwheat left a reserve of nitrates in the soil the millet crop very soon reduced the nitrate supply to 1 p.p.m. or less and kept it there throughout the balance of the season. The addition of 300 lb. per

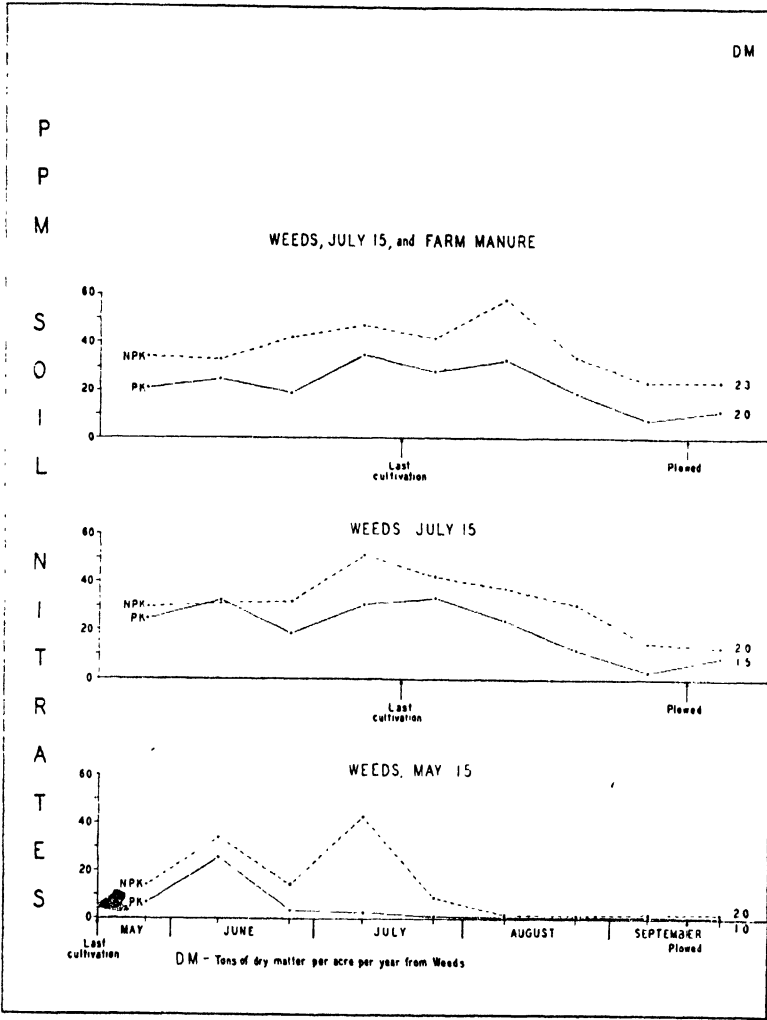


FIGURE 3. Soil nitrates, 1938-41, under weed green-manure crop from May 15 and July 15, the latter with and without farm manure and all three treatments with and without added nitrogen.

acre of sulphate of ammonia merely delayed for about two weeks the almost complete usage of nitrate though it did result in almost doubling the amount of dry matter obtained from the tops of the plants.

The Accumulation of Soil Nitrates under Weed Green-manure Crops with and without Farm Manure

When weeds were allowed to grow from mid-May onwards the soil nitrates were soon reduced to a low level (Figure 3) and nitrogen starvation symptoms appeared on the section which had received no sulphate of ammonia. The result was a yield of only 1 ton of dry matter per acre per year. Yellow foxtail, barnyard grass and old witch grass made up a high proportion of the weeds. The application of sulphate of ammonia to the adjoining section kept the nitrate supply higher throughout the season, gave a small proportion of lamb's quarters and pigweed, and doubled the yield of dry matter. However, even in this section the nitrates were reduced to about 2 p.p.m. from early August onwards.

Weeds allowed to grow from mid-July were of different species, mostly lamb's quarters and pigweed. These weeds did not show nitrogen starvation symptoms and, on the PK section gave a yield of dry matter of 1.5 tons per acre per year, a 50% increase over the weeds which started growing two months ahead of them. With nitrogen fertilization (NPK) the dry matter rose to 2 tons per acre per year, the same as the comparable section on which the weeds started two months earlier.

There was also a weed plot which received spring applications of 10 tons of farm manure per acre and on which the weeds are allowed to grow after mid-July. The weed population on this plot was similar to that on the comparable unmanured plot but reached somewhat higher amounts of dry matter (Figure 3). In the early part of the season there was not much difference in nitrates but later, the manured plot gave slightly higher readings.

DISCUSSION

In so far as the nitrate supply under a buckwheat green-manure crop is concerned there appears to be justification for using either legume hay or a mixture of straw and legume hay equal parts, as substitutes for farm manure whenever the cost of straw and hay compares favourably with farm manure. When no nitrogen was applied, half-rate applications of straw and farm manure seemed to be slightly less desirable than legume hay, and its mixture with straw both in nitrate accumulation and yield of dry matter. However, when nitrogen was added in the spring, the yield of dry matter in the buckwheat was equal to the other treatments, and nitrate accumulation in the top soil was very similar to them.

Millet, and weeds of the grass family allowed to grow after mid-May, kept the nitrates at a very low level. With millet, nitrates were reduced to 1 p.p.m. in about one month, and with weeds of the grass family, in about two months. On the sections where nitrogen was added, nitrates reached this low point about two weeks later in each case. It appears therefore that nitrogen starvation of the trees might result in orchards

where millet is sown about mid-May or weeds allowed to grow from that time. Instances of this condition have been seen in Experiment Station orchards and elsewhere in the Niagara District.

Buckwheat is probably a much safer green-manure crop to use where cultivation is being discontinued about the middle of May. For a green-manure crop starting in July, when the flush of tree growth is over, millet or weeds would probably be quite satisfactory. They might in fact be the best green-manure crops on rich soil where fruit colour is poor and winter injury a problem. However, if they are being followed by a crop of winter rye an application of quickly available nitrogen would be required for the best growth of the rye.

SUMMARY

1. Judged on the basis of dry matter of buckwheat as a green-manure crop and nitrate accumulation under that crop, either legume hay or straw or combinations of the two were satisfactory substitutes for farm manure. A combination of farm manure and straw was somewhat less satisfactory, and where straw was used by itself, even with adequate nitrogen, the growth of buckwheat was depressed.

2. Under buckwheat there was an almost continuous reserve of nitrate, whereas under millet, and weeds of the grass family, starting in mid-May, the nitrates were soon reduced to negligible amounts.

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance of the following students who, in the various years, took most of the nitrate readings: L. R. Webber, O. J. Phelan, K. Marsh, H. J. O'Reilly, and R. Morris.

HISTOLOGICAL OBSERVATIONS ON THE LOCATION OF PIGMENTS IN THE AKENE WALL OF THE SUNFLOWER (*HELIANTHUS ANNUUS L.*)¹

E. D. PUTT²

[Received for publication December 11, 1944]

Observations of the sunflower fruit, botanically an akene, but commonly referred to as a seed, show that it has three layers which may develop pigment independently of each other (5). The outer layer is the epidermis which may be entirely free of pigment or possess striped patterns of either dark brown or black colour. Below this appears a corky layer which may be either non-pigmented or solidly coloured with a purple pigment. Between the corky layer and the rigid portion of the fruit a solidly black or brown coloured layer is often found. No pigment, pigment in any one layer, or any combination of the pigments in these different regions may occur.

The purpose of the study herein reported was to determine the origin of these pigments in relation to the development of the ovary wall and their location in the mature fruit.

MATERIALS AND METHODS

Mature fruits from lines showing no pigment, striped pattern only, pigment in all three regions, and purple pigment of the corky layer and a striped pattern were studied. For the study of the development of the ovary wall and the pigment, a line having the innermost pigment layer and the striped pattern was used. Collections from this line were made during the summer of 1941 from plants varying in age from those in which the inflorescence initials were only about $\frac{1}{4}$ inch in diameter, to those with mature fruits. Bracts were removed from the earlier stages and then a portion of the involucre was fixed. In later stages several individual fruits were taken.

A form-acetic-alcohol solution consisting of 380 cc. of 70% ethyl alcohol, 10 cc. of glacial acetic acid, and 22 cc. of formalin (i.e. 40% or commercial formaldehyde) was used for fixing and storing.

Immediately after collection and immersion in the fixing agent the material was subjected to a vacuum, created by a tapwater suction pump, for 1 to 2 hours. The decrease in volume following this treatment was made up with 70% ethyl alcohol.

Ethyl alcohol was used for dehydration. After reaching 100% alcohol, the material was allowed to remain in it for 24 hours and then passed through a xylol-alcohol series consisting of 2 $\frac{1}{2}$, 5, 10, 15, 25, 50, 75 and 100% xylol. Stages up to 4 days after flowering required about 80 hours and later stages about 140 hours for the complete series.

Because of the rigid nature of the later stages a rubber-beeswax-paraffin mixture (3) was chosen for embedding to facilitate sectioning. The mixture consisted of 100 grams of parowax, 4 to 5 grams of rubber-

¹ A summary of studies conducted under the direction of Dr. C. R. Burnham, Department of Agronomy and Plant Genetics, University Farm, St. Paul, Minnesota.

² Formerly Agricultural Assistant, Dominion Forage Crops Laboratory, Saskatoon, Saskatchewan, now temporary Extension Assistant, Poultry Department, Ontario Agricultural College, Guelph, Ontario.

paraffin stock mixture and 1 gram of beeswax. The rubber-paraffin stock mixture was prepared by dissolving 20 grams of raw rubber in 100 grams of smoking hot paraffin. Preparation for embedding required about 55 hours for the earlier stages and 100 hours for the later stages.

Sections were cut with a rotary microtome at 12.5 microns in the earlier stages and 17.5 and 20 microns for the later stages. Acid fuchsin (1% in 70% ethyl alcohol) was used for staining.

OBSERVATIONS

Cross, radial and tangential sections with reference to the individual ovary or fruit are discussed. Unless otherwise indicated, the statements in this section refer to fruits possessing the inner layer of pigment and the striped pattern, but no purple colour.

The earliest stage examined, which was about two weeks prior to flowering, showed the ovary wall as a mass of parenchymatous tissues with the exception of the outer single layer of epidermal cells. Approximately 4 days before flowering the ovary wall exhibited a characteristic structure as shown in the cross section of Figure 1. Under the epidermis a single layer of cells was clearly differentiated. A row of vascular bundles was evident. Numerous ray-like structures extending from the outer level of the vascular bundles to the epidermis were also present.

Further development up to 1 day after flowering showed the layer of cells under the epidermis to be cork initials in which periclinal division had occurred as seen in Figure 2a, a cross section through the central part of the ovary wall. At this stage the first appearance of pigment was also observed in the upper part of the ovary as shown in Figure 2b, a cross section through the upper portion of the same ovary as illustrated in Figure 2a. Its appearance is also shown in tangential view in Figure 3. This was the first appearance of the innermost coloured layer which in gross morphological studies shows about 6 days after flowering. The most striking feature of this pigmented material was its intercellular rather than intracellular nature. It appeared in small patches between the cork layer and adjoining inner tissue but conformed to no cellular shape or pattern. Subsequently, these patches increased in size and coalesced to form an amorphous black band with points jutting into the cork layer. These points were probably formed by the material filling in the cavities between the cork cells. This condition is shown in Figures 4 and 5 which are a cross and a radial section of fruits 17 and 25 days after flowering, respectively. Radial sections made at these stages also showed the pigment was present between the cells of the ray-like structures.

In addition, Figures 4 and 5 show the pigment of the epidermis. Figures 6 and 7 complete the account. The former shows a cross section through the juncture of a black and a white stripe in a mature seed possessing a striped pattern only, while the latter is a section of a mature seed showing the pigment in all three regions. The preparation in Figure 7 was not stained.

It was apparent that the pigment of the striped pattern was carried in the epidermis and is intracellular in nature. It was also seen from section illustrated in Figure 6 that the structure of the pigmented and non-

pigmented epidermal areas of the striped seed was similar. The cork layer of the fruit illustrated in Figure 6 was thinner than in the other figures in which the inner layer of pigment was present. However, sections of other striped seeds without the inner layer of pigment showed that the cork layer may be as thick as that in Figures 4, 5 and 7. Examination of white seeds showed similar cell structures with the entire absence of the inner pigment band or any non-pigmented structure in that location.

In addition to showing the pigment of the epidermis and the inner pigment band, the section of Figure 7 also showed the heavy pigment in the cork layer itself. While it could not be seen in this section, since the pigment of the cork layer was purple, it was likely anthocyanin in nature and thus would be intracellular. This possibility may be checked by plasmolysis studies in living tissue.

The sections of the last four figures also showed that the parenchyma below the cork layer became sclerenchymatous, thus formed the rigid part of the seed. The characteristic thick-walled cells were seen in cross sections, while the view of Figure 5 showed the pits found in the cell walls of such tissue.

Investigations were not conducted to determine the chemical nature of the pigments. As stated above, it was felt the purple pigment of the cork layer was an anthocyanin. The inner layer, judging by its amorphous nature and the manner in which it filled in between the cells, was a resinous substance. No suggestion concerning the nature of the striped pigment can be made from the studies reported here.

DISCUSSION

Putt (5) has reported that the presence of pigment in the inner layer is dominant to its absence and dependent on a single genetic factor difference. Platchek (4) in earlier work with the "armour layer"; which, judging by his reports as well as those of Arnoldova (1) is synonymous with the inner layer discussed here, had also found the difference dependent on a single factor pair with pigmentation dominant. From an economic standpoint this is a valuable observation since Platchek credits the "armour layer" with resistance to larvae of the moth *Homocosoma nebulella*. Bird and Allen (2) report economic damage to seed crops of sunflowers caused by the larvae of *H. electellum* in Manitoba in 1936. The writer has also observed the same insect damaging heads of a seed crop in Saskatchewan in several seasons, affecting as high as 15% of the plants in 1937. While not the same species name as the insect observed by Platchek, the one in Western Canada is no doubt closely related and may be synonymous. Though Platchek through his term "armour layer" implies a mechanical resistance, the writer in the present study has found the thick layer of sclerenchyma to be similar in both types of fruits. The resistance appears rather to be contributed by the inner pigment itself and thus to be physiologic in nature through repulsion of or toxicity to the insect larvae.

With the recent expansion of acreage of sunflowers being produced for seed in Western Canada the population of this insect, *Homocosoma electellum*, will likely increase. Consequently, the incorporation of the inner

pigment layer with its associated insect resistance into new varieties appears to be a highly desirable objective of the breeding program. Because of the simplicity of its inheritance this objective could be easily attained.

The economic aspects of the other pigments observed are not yet known. Nor is much known concerning their inheritance. Preliminary observations indicate that the purple condition and the absence of striping are dominant to their respective contrasting characters. Segregating generations indicate complex inheritance.

SUMMARY

1. Histological studies of the wall of sunflower ovaries and fruits at stages ranging from before flowering up to maturity are reported.
2. The striped layer of pigment is contained in the epidermis of the ovary wall and is intracellular.
3. Purple pigment, believed intracellular, is found in the cork layer immediately below the epidermis of the ovary wall.
4. The inner pigment layer consists of an amorphous darkly pigmented substance which fills the intercellular spaces between the cork layer and the adjoining sclerenchyma tissue. It may be a resinous material.
5. No structural difference was observed between fruits with and without various pigments.
6. The amorphous layer appears to be synonymous with the "armour layer" of Platchek. Since he credits it with resistance to larvae of the moth *Homoeosoma nebullela* the incorporation of this layer into new varieties of sunflowers for seed production seems desirable.

REFERENCES

1. ARNOLDOVA, O. N. To the biology of sunflower blooming in connection with the technics of its crossing (Translated title). J. Expt. Landw. Sudost. Eur. Russ. 3 : 131-143. 1926.
2. BIRD, R. D., and W. R. ALLEN. An insect injuring sunflowers in Manitoba. Canadian Entomologist 68 : 93-94. 1936.
3. HANCE, ROBT. T. A new paraffin embedding mixture. Science 77 : 353. 1933.
4. PLATCHEK, E. M. Inzucht in der Anwendung zur Selektion der Sonnenblume. Zhurn. Opytn. Agro. Iugo-Vost J. Expt. Landw. Sudost. Eur. Russ. 4 : 120-149. 1927. German Summary.
5. PUTT, E. D. Observations on morphological characters and flowering processes in the sunflower (*Helianthus annuus* L.) Sci. Agric. 21 : 167-179. 1940.

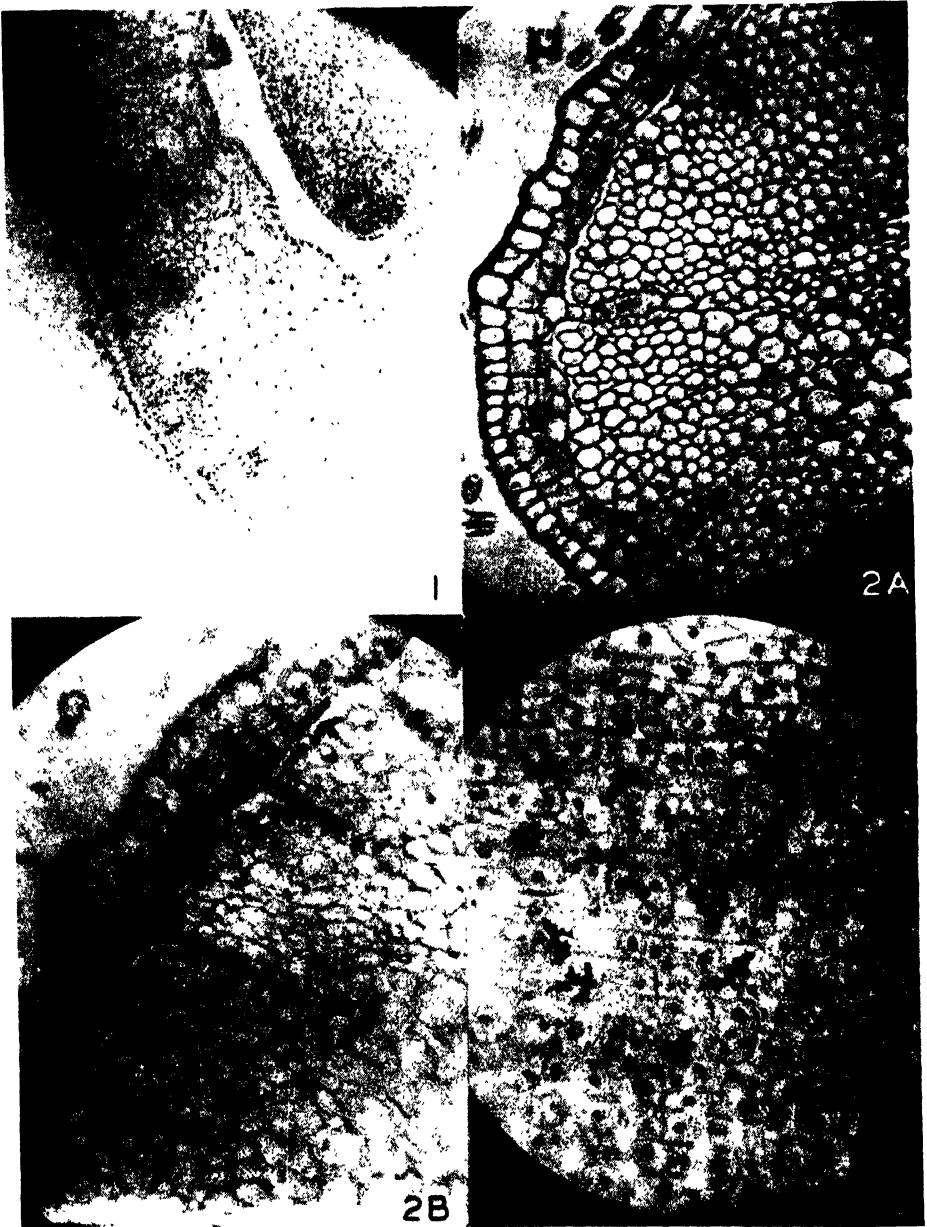


FIGURE 1. Cross section of ovary wall 4 days before flowering showing epidermis, single layer of cells below it, vascular bundles and numerous ray-like structures extending from vascular bundles to epidermis.

FIGURE 2. Cross section 1 day after flowering.

(a) In the central part of the ovary showing periclinal divisions in the layer of cells below the epidermis.

(b) In the upper part of same ovary showing first appearance of the inner amorphous pigment layer.

FIGURE 3. Tangential section 1 day after flowering showing early appearance of the inner amorphous pigment layer.



FIGURE 4. Cross section 17 days after flowering showing tendency of inner amorphous pigment layer to fill intercellular spaces and also the early appearance and intracellular location of the epidermal pigment.

FIGURE 5. Radial section 25 days after flowering showing inner amorphous pigment layer filling intercellular spaces of cork layer intracellular nature of epidermal pigment and pits characteristic of sclerenchymatous tissue.

FIGURE 6. Cross section through junction of black and white stripe of mature fruit possessing epidermal pigment only. Note similarity of structure compared with fruits possessing other pigment.

FIGURE 7. Unstained cross section of fruit possessing epidermal pigment, purple pigment in cork layer and also the inner amorphous pigment layer.

SOME FACTORS AFFECTING APPLE YIELDS IN THE OKANAGAN VALLEY

I. TREE SIZE, TREE VIGOUR, BIENNIAL BEARING, AND DISTANCE OF PLANTING¹

J. C. WILCOX²

Dominion Experimental Station, Summerland, B.C.

[Received for publication September 6, 1944]

The major apple producing section of British Columbia is in the Okanagan Valley and adjacent areas, in the southern interior of the province. For a number of reasons—some known, some unknown—the yield of apples in the Okanagan has not been as high on the average as has seemed desirable. For example, data compiled by the British Columbia Department of Agriculture (3) are summarized in Table 1. It will be seen that over a 4-year period, the average production per acre was only

TABLE 1.—APPLE ACREAGE AND PRODUCTION IN THE OKANAGAN VALLEY, 1937 TO 1940*

Variety	Acreage†	Average annual yield	Yield per acre‡
	acres	boxes	boxes
McIntosh	4,788	1,739,000	456
Delicious	3,418	628,000	270
Jonathan	2,122	616,000	342
Newtown	1,626	366,000	318
Winesap	1,380	224,000	330
Wealthy	981	271,000	288
Rome Beauty	904	246,000	312
Stayman	452	88,000	354
Duchess	209	57,000	300
Others	2,317	974,000	306
Total	18,197	5,209,000	378

* Compiled from data supplied by the British Columbia Department of Agriculture.

† Acreage in 1940, including both bearing trees and young trees.

‡ Based on assumption that production is almost entirely from trees 10 or more years old.

378 packed bushel boxes. The McIntosh variety contributed the most, both in total acreage and in yield per acre. Even the average McIntosh yield of 456 boxes per acre, however, cannot be considered impressive. As noted later in this report, this variety can and does produce—under favourable circumstances—up to 1000 packed boxes per acre per year.

Both research and observation indicate that a large number of factors have been instrumental in limiting apple yields in the Okanagan Valley. Some of these factors may be classed as directly nutritional in nature, others as only indirectly nutritional or as non-nutritional. Among the latter two classes may be mentioned codling moth, apple scab, crown rot, and winter injury, which are the subjects of research by representatives of both the Dominion and Provincial Departments of Agriculture. The

¹ Contribution No. 636 from the Division of Horticulture, Dominion Experimental Farms Service, Canada. This paper is a condensation of part of a thesis presented to the State College of Washington in partial fulfilment of the requirements for a Ph.D. degree in Horticulture.

² Assistant Superintendent in charge of nutritional investigations with tree fruits.

nutritional phase of the problem has also received much attention, partly through field tests of fertilizers, partly through minor element studies, and partly through soil and tissue analyses. In studies of the major elements conducted by the author, both the field application and analysis methods have been used.

In 1937, an investigation was started to determine the relationships between certain selected factors and apple tree performance. The primary factors selected for study were size of tree, distance of planting, vigour of tree, biennial bearing, N-P-K-Ca-Mg status of the tree, P-K-Ca-Mg status of the soil, soil texture, soil depth, soil pH, soil organic matter, moisture holding capacity of the soil, and root distribution. It was desired to determine the effects of these factors on mature, bearing trees growing under typical orchard conditions. The type of investigation decided upon, therefore, was a survey of selected groups of trees growing under a wide variety of conditions, the recording of the required data from these trees and from the soil, and the examination of these data by suitable statistical procedures. Most phases of this investigation have now been completed, and it is proposed to report the findings in a series of papers. This present paper covers the relationships found among tree size, tree vigour, biennial bearing, distance of planting, and tree yield.

REVIEW OF LITERATURE

No attempt will be made at this time to review in detail the relationships between nutritional factors and apple tree performance. It will be considered sufficient to note some of the major findings by other workers with respect to the three primary factors discussed in this paper; that is, size of tree, vigour of tree, and biennial bearing.

Size of Tree

A review of the literature on this factor will be found in a previous paper by the author (20). In that paper, it was reported that as McIntosh trees increased in size, the yield tended to increase. This increase was in direct proportion to the geometric mean of the circumference and the cross-sectional area of the trunk. It was found that in computing the per-acre yields, it was advantageous to relate the size of tree to the area of ground occupied per tree. In 1941, Overholser, Overley and Wilcox (12) reported highly significant positive correlations with Jonathan and Rome trees between both trunk circumference and trunk area on the one hand and yield of apples on the other hand.

Tree Vigour

Work done prior to 1937 on the relationship between tree growth and tree yield has been reviewed previously by the author (18). In 1937, Overholser, Overley and Barnhill (11) reported positive correlations between terminal length and increase in trunk circumference on the one hand and yield of apple trees on the other hand. In 1941, Overholser, Overley and Wilcox (12) reported highly significant positive correlations between terminal length and yield with Jonathan, but not with Rome or Winesap; and between increase in trunk circumference and yield with Jonathan and Winesap but not with Rome.

Biennial Bearing

It has occasionally been reported by investigators (14) that trees bearing biennially do not bear as heavily over a period of years as do trees bearing annually. The data supporting this contention, however, appear to be somewhat meagre.

Biennial bearing has been found by a number of workers to be influenced by the vigour of the trees. Roberts (13) reported in 1920 that high vigour was needed to maintain annual bearing. For annual bearing of the McIntosh, at least 12 to 16 inches of terminal growth were required. Since then he has reported similar findings (14). Bradford (2) found annual bearing to be induced by spring applications of nitrogenous fertilizers. Hooker (10) obtained similar results with fall applications. Harley and his co-workers have reported at different times (7, 8) that a high degree of vigour is necessary if other methods of inducing annual bearing are to be effective. A high degree of vigour by itself, however, was not found sufficient to induce annual bearing. This last has also been reported by Dorsey (5), Auchter and Schrader (1), Dickson (4) and Wallace and Spinks (16), who have increased tree vigour by pruning and by fertilizing with nitrogen, but have had little success from these treatments alone in overcoming biennial bearing.

Biennial bearing has been shown by a number of workers to cause differential effects on tree growth in two successive years. The literature on this prior to 1937 was covered by the author in a previous paper (18). In that paper, it was reported that the increase in trunk circumference was greater in the off year, but that the reverse was true of the terminal length. Similar findings were reported by Overholser, Overley and Wilcox (12) in 1941.

PROCEDURE

Selection of Trees

Only one variety of apple, the McIntosh, was used in this investigation. In 1937, some 400 bearing McIntosh trees were selected in grower-owned orchards. A deliberate attempt was made to include all the major soil series found in the irrigated part of the Okanagan Valley, as well as a wide variety of cultural treatments. The purpose in doing this was to include trees differing widely in bearing ability and in the factors being studied. Five McIntosh trees were selected in each plot of three fertilizer experiments in grower-owned orchards³; and in each of a number of other orchards, one or two groups of trees were chosen, usually with 5 trees to a group. Some groups were in straight rows, some in solid blocks. For want of a better term, these groups were called "plots." Except in the three special fertilizer experiments, all orchard operations (including fertilizing) were conducted by the growers in accordance with their own orchard routine.

Considerable care was exercised in selecting the trees. It was required that they be bearing, and mature or nearly so (Figure 1); that they appear healthy; and that they be well cared for by the growers, except in so far as fertilizing was concerned. Failure to fertilize, or to do so in what

³ Two of these experiments were conducted by Mr. B. Hoy, of the British Columbia Department of Agriculture, and one was conducted by the author.

appeared inadequate amounts, was considered desirable in a certain proportion of the plots. Actually, a wide variation in the kind and amount of fertilizer used was included. The distance apart of the trees varied from 25×25 feet on the hexagonal to 35×35 feet on the square. In spite of the care in selection, it was found necessary in 1938 and 1939 to eliminate a number of plots. One reason was that the tree yields were found not to be suitable for comparison purposes unless each tree was surrounded on all sides by other trees of similar size and condition (20), and a number of the plots had been poorly selected in this respect. In addition, a few

TABLE 2.—PLOT AND TREE DISTRIBUTION

—	Plot letter	No. of growers	No. of plots	No. of trees
Penticton	P	4	9	35
Summerland	S	2	2	10
Trepanier	T	3	6	23
East Kelowna	K	10	23	95
Belgo	B	6	10	46
Glenmore	G	4	7	32
Winfield	W	4	7	29
Oyama	O	4	4	20
Total		37	68	290

growers were unable to assist in recording the yields. These plots were partially replaced by others, selected in 1938 and 1939. The numbers of plots and trees finally used in each district are summarized in Table 2, and the 290 trees selected for statistical analysis are listed individually in Table 9 in the Appendix.

Tree Records

From 1937 to 1942, records were taken annually on trunk circumference, terminal length, total yield, and "profitable" yield (from 1939 only). In addition, observational notes were taken on disease and insect injury, fertilizer treatment, cover crop treatment, methods of irrigation, degree of thinning, type and severity of pruning, and any other factor that it was felt might have a bearing on the results.

The methods used in recording the trunk circumference and terminal length have already been described (17, 18). Both were measured in centimetres, to the nearest 0.1 centimetre. The terminal length procedure was shortened somewhat by selecting only 10 typical terminals per tree, and by measuring them consecutively along a steel tape and recording the total only. From the trunk circumference were calculated the cross-sectional area of the trunk, and the geometric mean between this and the trunk circumference. This last was found previously by the author (20) to be the best index of size of tree with the McIntosh, and was the one used in reaching the final conclusions in this investigation. To obtain a measure of tree size per unit of ground area occupied, the "geometric mean" was divided by the area of ground occupied per tree, in square feet (20). This measure was called the "trunk-ground ratio."

Terminal shoots were collected just prior to harvest in 1939 and 1940, for chemical analysis. The tip 5-cm. portions of 20 twigs per tree were selected each year, from the same type of terminal as was used for measuring terminal lengths. These twigs were dried and weighed, and the weights used as an indication of twig diameter. The chemical analyses will be reported in a subsequent paper.

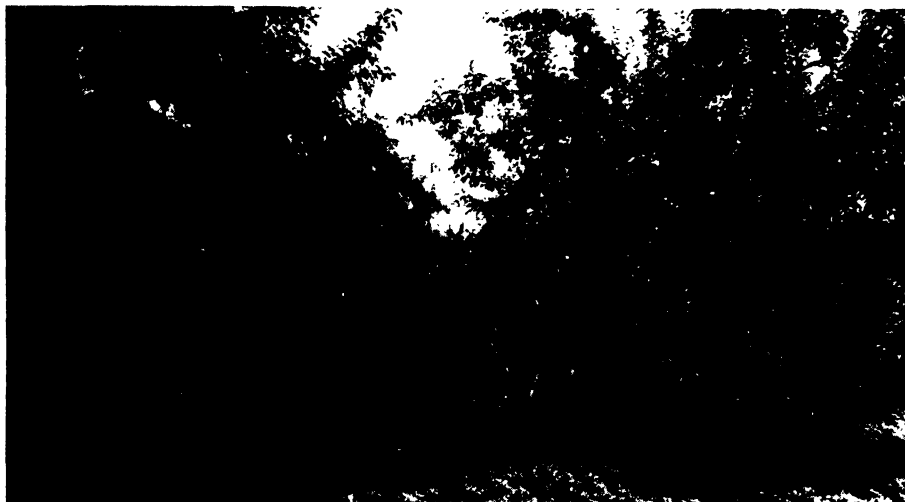


FIGURE 1. Plot K54. In this plot, the trees were starting to meet in the centres. This was typical of a high percentage of the McIntosh plots.

To obtain the yield per tree, a tag was tacked to each tree prior to picking, and the grower marked down the number of loose bushel boxes picked, to the nearest half box. The accuracy of these records was checked by careful preharvest estimates. In a few cases, they were found to be unreliable and so were not used. The total yield per tree was obtained by adding together the boxes recorded at each picking plus the fruit on the ground. It was multiplied by the trees per acre to obtain the yield per acre.

In addition to total yield, "profitable" yield was recorded. This was considered to be fruit that showed 20% or more of solid red colour and that fell within the diameter range of $2\frac{1}{4}$ to $3\frac{1}{8}$ inches. Insect, disease, and mechanical injuries were ignored in making this classification. Just prior to harvest, careful estimates were made by three experienced workers of the "non-profitable" fruit on each tree. These estimates were checked by grading the fruit from a number of the trees. Deducting the non-profitable yields from the total yields gave the profitable yields.

The total yield per tree was used in determining the degree of biennial bearing. From the yields of each two consecutive years was calculated their "biennial bearing index," as follows:

$$\text{Biennial bearing index} = \frac{100 (\text{difference between two yields})}{\text{sum of two yields}}.$$

Complete annual bearing gave an index of zero, and complete biennial bearing an index of 100. When the yield of the second year was the heavier, the index bore a plus sign; and when the yield of the first year

was the heavier, it bore a minus sign. In computing averages over a period of years, these signs were ignored. The biennial bearing index is a modification of the "I value" used by Hoblyn, Grubb, Painter and Wates (9). Biennial indices were also calculated for increase in trunk circumference, for terminal length, and for twig weight.

Statistical Analysis

Wherever the data were available, averages were calculated for each two successive years (i.e. for 1937 and 1938, for 1938 and 1939, etc.), and for each four successive years (i.e. 1937 to 1940, 1938 to 1941, and 1939 to 1942). In addition, averages were determined for five-year periods in certain cases, where the biennial bearing status changed during the course of the investigation. This will be discussed more fully under "Results." Primarily because of changes in the biennial bearing status, some periods were considered to provide more reliable averages than others. For a final summary of the data, the most reliable four- and five-year averages were used. These are presented in Table 9 in the Appendix, and the periods used in calculating the averages are indicated.

The principal methods used in analysing the data were correlation, regression, analysis of covariance, and scatter diagram studies (6, 15). In order to obtain data for further scatter diagram studies, the individual yields were adjusted, in order, for differences in size of tree, in tree vigour and in biennial bearing, by the covariance method. The data used to represent these three factors were trunk-ground ratio, terminal length, and biennial bearing index, respectively. The same studies were then made on these adjusted yields as were made on the unadjusted yields.

A scatter diagram was prepared for each pair of data correlated. By this means, it was possible to observe any wide deviations from the general trends. In each scatter diagram involving yield, also, an examination of the points was made in an attempt to determine approximately the "line of maximum yields." In most charts involving yield, the highest yields show some degree of continuity across the chart, such that a line could be drawn through the general area of these highest points. This line, therefore, represented approximately the highest yields actually obtained at each value of the factor concerned. It has proved useful in several ways; for example, setting standards of production toward which apple growers in the Okanagan should aim, and in indicating approximately the optimum values of the factor concerned.

RESULTS

So many records have been obtained during the six-year period that it would not be feasible to report all of them. It will be considered sufficient to present the most pertinent parts of the "summary" data, which will be found in Table 9 in the Appendix. For the most part, the findings obtained from analysing the summary data are of the same nature as those obtained from the two-year averages and from the other four-year averages. In order to shorten the presentation, accordingly, the findings from the summary data are the ones stressed in this paper. Where there has been any deviation from the "summary" results, this will be noted.

Changes in Biennial Bearing Status

Most of the 290 trees selected for study showed consistency in their yield progression. Some were completely biennial bearers and some almost completely annual bearers, with all stages between represented. In view of the fact that the profitable yields were not recorded until 1939, the summary data for the trees showing no breaks in progression were obtained by averaging the records for the four years 1939-42.

Quite a number of the trees did show breaks in their yield progression. These breaks commenced in some plots with exceptionally heavy yields in 1940, due to causes unknown, and in some plots with very light yields in 1941, due apparently to frost injury and tarnished plant bug. The effects of the 1940 conditions may be illustrated with four trees, whose yields (in boxes per tree) from 1937 to 1942 were as follows:

	1937	1938	1939	1940	1941	1942
B34E:	5	46	0	47	2	36
K25A:	44	0	59	37	30	37
K7B:	19	6	27	29	0	22
K7D:	20	24	28	41	0	24

With tree B34E, the yield progression was not affected. With tree K25A, biennial bearing was changed into almost-annual bearing. With tree K7B, the year of heavy bearing was changed. And with tree K7D, almost annual bearing was changed into definitely biennial bearing. The years selected for the summary data were 1939-42 with tree B34E, 1938-42 with trees K25A and K7D, and 1938-41 with tree K7B. The exceptionally light crop in some plots in 1941 had just the opposite effects on the yield progression.

Some Effects of Biennial Bearing

The effects of off-and-on-year bearing on the growth of the trees were determined by means of correlations between each pair of biennial indices. The results for 1939-40 are summarized in Table 3. An examination of the records for each two successive years reveals that the relationships indicated in this table were not confined to the 1939-40 data, but were general. Certain conclusions appear to be justified, as follows:

TABLE 3.—CORRELATIONS BETWEEN 1939-40 BIENNIAL INDICES

Two sets of data correlated		Coefficient of correlation
Biennial bearing index	Biennial trunk index*	-.729 (HS)†
Biennial bearing index	Biennial terminal index	+.634 (HS)
Biennial bearing index	Biennial twig weight index*	-.625 (HS)
Biennial trunk index	Biennial terminal index	-.536 (HS)
Biennial trunk index	Biennial twig weight index	+.520 (HS)
Biennial terminal index	Biennial twig weight index	-.561 (HS)

* "Biennial trunk index" is short for "biennial increase in trunk circumference index." "Twig weight" refers to the weight of the tip 5 cm. of the terminal shoots.

† HS stands for highly significant, with odds greater than 99 : 1.

1. In the on year, the increase in trunk circumference was considerably less than in the off year. This was definitely the closest relationship of those reported in Table 3.

2. In the on year, the terminals tended to be longer than in the off year. As noted in a previous paper by the author (18), this is no doubt a secondary relationship; that is, the length of terminal is dependent in large measure on the amount of food stored the previous season, which in turn is directly dependent on the size of crop that same year.

3. In the on year, the twigs tended to be lighter than in the off year. This may be explained by the fact that in the on year the annual thickness in new growth is less all over the tree (18). As confirmation of this, there was a high positive correlation between the year of heavy twigs and the year of large increase in trunk circumference.

4. As would be expected from the above relationships, there were strong tendencies for both the increase in trunk circumference and the twig weight per unit length to be high the same year that the terminals were short.

These findings corroborate those reported previously by the author (17, 18). It is apparent that when the general relationship between any one factor and yield is being studied, a single year's records are not as reliable as are two-year or four-year averages.

The standard deviations of the 1939-40 data used in the above correlations were as follows:

Biennial bearing index	52.5
Biennial trunk increase index	24.3
Biennial terminal index	18.2
Biennial twig weight index	8.2

Each index has a mean of approximately zero. The higher the standard deviation, therefore, the greater were the relative differences between the 1939 records and the 1940 records; that is, the greater was the "biennial" tendency.

Summary Data

The minima, maxima, means, and coefficients of variability of the principal summary data are shown in Table 4. It will be noted that there was a wide range of values represented by each type of measurement.

TABLE 4.—RANGE AND VARIABILITY OF SUMMARY DATA

Measurement	Minimum	Maximum	Mean	Coefficient of variability*
"Total" yield, in loose boxes per acre	503	1982	1098	26.6
"Profitable" yield, in loose boxes per acre	436	1592	941	25.6
Trunk-ground ratio	0.20	0.61	0.34	20.3
Increase in trunk circumference, in cm.	1.21	5.60	2.69	29.3
Terminal length, in cm.	11.5	42.9	25.5	20.0
Biennial bearing index	2	100	51	48.6

* The coefficient of variability is obtained by dividing the standard deviation by the mean, and multiplying by 100.

This was especially true of the biennial bearing index, which showed an exceptionally high coefficient of variability. A comparison with Table 1 indicates that the yields on these 290 trees averaged somewhat higher than the McIntosh mean for the Valley, even after taking into account the fact that it requires about 10 loose boxes to fill 7 packed boxes.

Summary Correlations

Some of the more important correlations that were obtained from the summary data are presented in Table 5. Only those partial correlations are shown that it was considered might add to the general information. For the most part, the coefficients indicated are similar to those obtained in each of the two-year periods from 1937 to 1942. Some exceptions to this general agreement, however, will be noted. Among the more important relationships revealed by the correlations are the following:

TABLE 5.—SOME CORRELATIONS OBTAINED FROM THE "SUMMARY" DATA

Two sets of data correlated		Factors eliminated	Coefficient of correlation
Trunk-ground ratio	Terminal length	None	+ .042 (NS)*
Trunk-ground ratio	Biennial bearing index	None	+ .049 (NS)
Terminal length	Biennial bearing index	None	- .064 (NS)
Total yield	Trunk-ground ratio	None	+ .427 (HS)
Total yield	Terminal length	None	+ .252 (HS)
Total yield	Terminal length	Trunk-ground ratio	+ .260 (HS)
Total yield	Biennial bearing index	None	- .441 (HS)
Total yield	Biennial bearing index	Terminal length	- .442 (HS)
Total yield	Biennial bearing index	Trunk-ground ratio Terminal length	- .526 (HS)
Total yield	Trunk increase	Trunk-ground ratio	+ .144 (S)
Profitable yield	Trunk-ground ratio	None	+ .389 (HS)
Profitable yield	Terminal length	Trunk-ground ratio	+ .087 (NS)
Profitable yield	Biennial bearing index	None	- .388 (HS)
Profitable yield	Biennial bearing index	Trunk-ground ratio	- .450 (HS)

* NS—Non-significant, with odds less than 19 : 1.

S—Significant, with odds between 19 : 1 and 99 : 1.

HS—Highly significant, with odds greater than 99 : 1.

1. Size of tree. An increase in size of tree (as measured by the trunk-ground ratio) was accompanied by no significant change in terminal length or in degree of biennial bearing. There does not appear to be any fundamental relationship represented by these correlations. As would be expected, however, the larger trees tended to bear heavier crops.

2. Terminal length. In view of the findings already noted by other investigators (2, 8, 10, 13, 14), the low correlation between terminal length and biennial bearing index is rather surprising. It should be noted that in 1937-38 this correlation was -0.320 , and in 1940-41 it was -0.156 , both "significant." Even assuming that there has been some effect of vigour on biennial bearing, the indications are that certain other factors have had a still greater effect. Observation indicates that these other factors are primarily meteorological in nature, in the area included in this investigation.

3. Increase in trunk circumference. The correlation between trunk increase and total yield was distinctly lower than that between terminal length and total yield, which contrasts with the higher correlation (already noted) between trunk increase and yield in any one year. This finding is interpreted as indicating that with the trees used in this investigation, those conditions in the tree associated with the terminal growth have, over a period of years, been more directly related to total yield than have those conditions associated with trunk growth. This points to terminal length being the more useful measure of tree vigour in routine work. As suggested previously by the author (19), however, both measurements are distinctly useful for this purpose.

4. Biennial bearing. It is sufficient to note that all correlations between biennial bearing and yield have been negative and "highly significant." In other words, there has been a marked tendency for the trees bearing biennially to have both lower total yields and lower profitable yields than those bearing annually.

Scatter Diagram Studies

Scatter diagrams were made of every pair of factors correlated. By this means, any abnormalities in the general trends were determined. Two different types of distribution are illustrated in Figures 2, 3 and 4. In the first type (Figures 2 and 4), the distribution shows a consistent trend in the one direction. The trend is positive in Figure 2, and negative in Figure 4. In the second type (Figure 3), the trend appears to change as the factor increases.

As already noted under "Procedure," maximum-yield lines were drawn in each scatter diagram involving yield. In most of the diagrams, these lines showed the same general trends as did the regression lines (Figure 2). An exception to this was where profitable yield was plotted against terminal length (Figure 3). The contrast between this and total yield plotted against terminal length was both marked and consistent, not only with the summary data but also with the two-year averages. As the terminal length increased, the maximum line of total yield increased steadily throughout almost the whole range (Figure 2), but the maximum line of profitable yield increased to a maximum at a terminal length of 25 to 30 cm. and then decreased again (Figure 3). When profitable yield was

plotted against terminal length within the highest frequency size groups of the other major factors, the results were practically the same. There is thus no evidence that the change in direction of the line of maximum yields was due to interaction between factors.

When a correlation is close to zero and the slope of the regression line is very low, it is usual for the distribution of points in the scatter diagram to assume an oval shape. In such a case, the line of maximum yields tends to rise to a maximum and to fall again. The question arises as to whether this might be the primary cause of the shape of the line of maximum yields

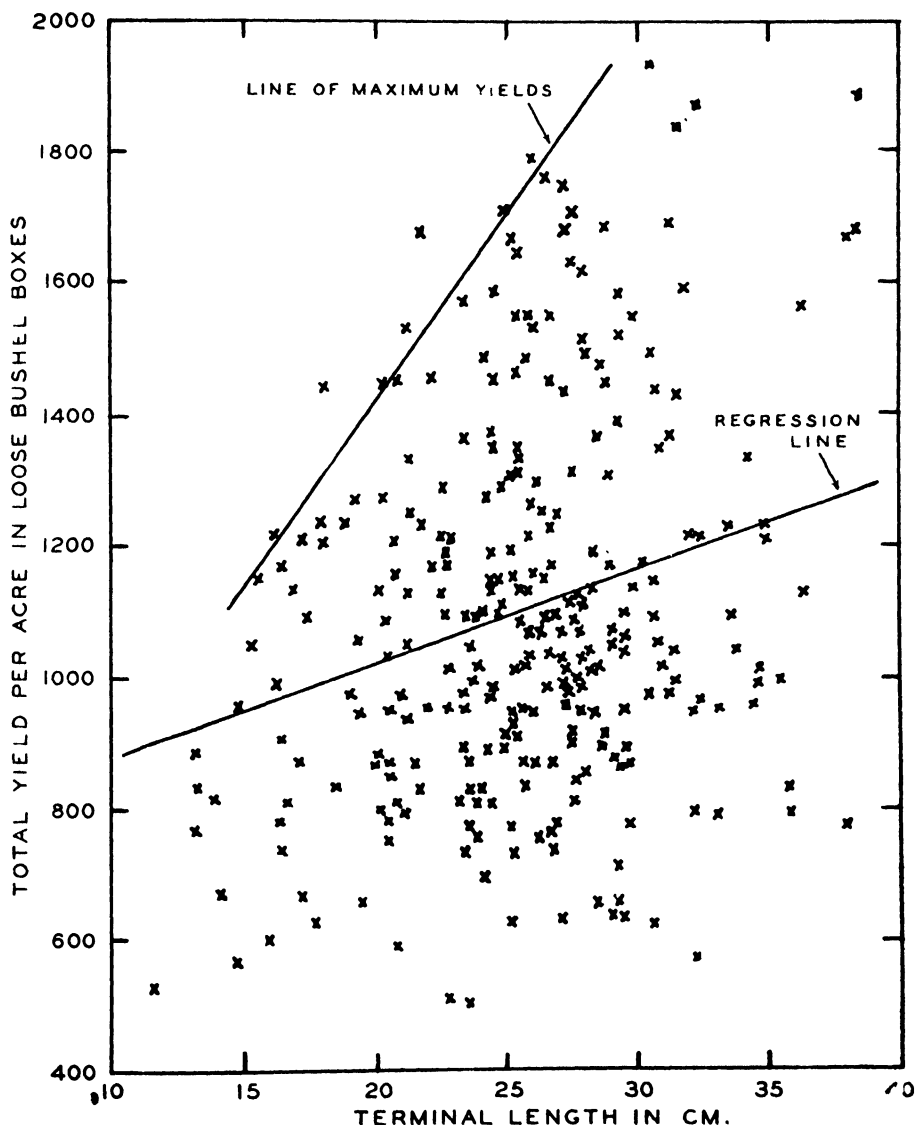


FIGURE 2. Scatter diagram of total yield per acre plotted against terminal length. The yields have been adjusted for differences in size of tree. $r = +0.260$ (Table 5).

in Figure 3. A comparison with a large number of other scatter diagrams representing low correlations indicates that it is not. It is not usual for the rise and fall to be as steep in relation to the ranges of the factor and function as they are in Figure 3.

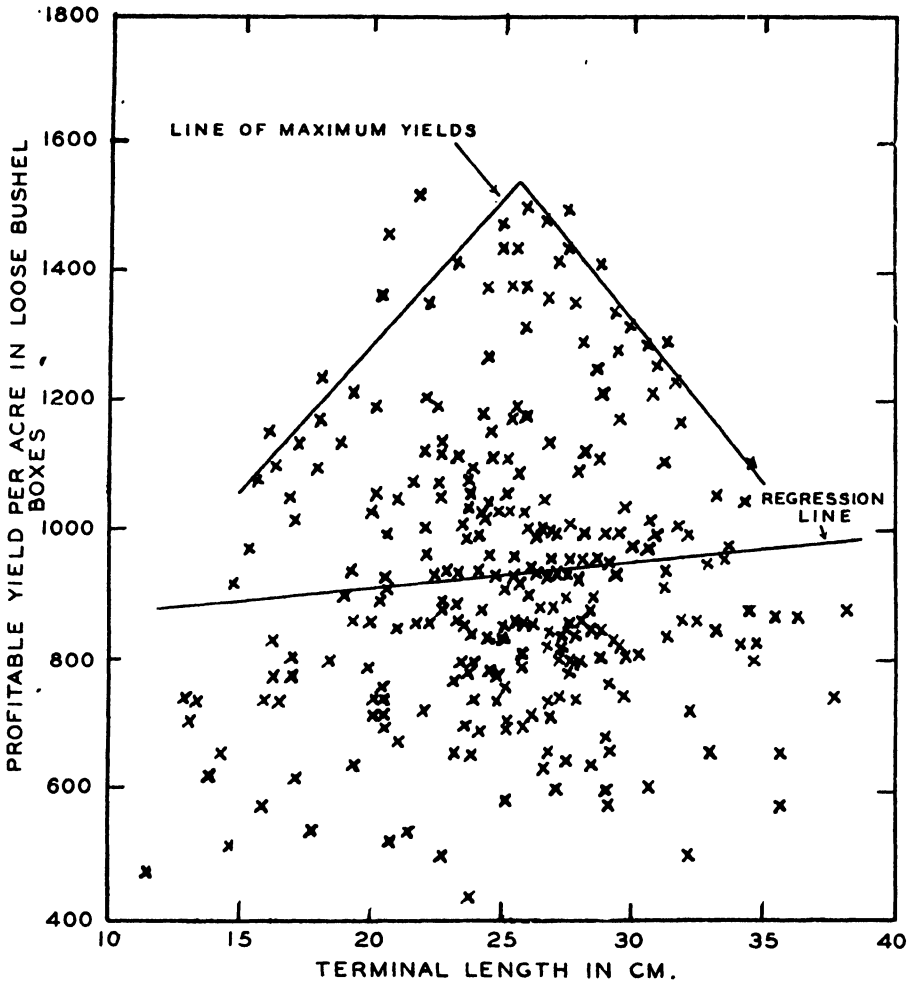


FIGURE 3. Scatter diagram of profitable yield per acre plotted against terminal length. The yields have been adjusted for differences in size of tree. $r = +0.087$ (Table 5).

The second degree polynomial regression line (6, 15) of the distribution in Figure 3 was found to be a curve with the equation

$$y = 1040 - 1.075x - .01865x^2,$$

in which y = profitable yield per acre,
and x = terminal length.

The maximum point on this curve comes at a terminal length of 28.8 cm. The sum of the squared deviations of yields, from this curvilinear regression line, is not significantly different from that of the rectilinear

regression line. However, the curvilinear line was considered to provide further evidence that the optimum terminal length lay somewhere between 25 cm. and 30 cm.

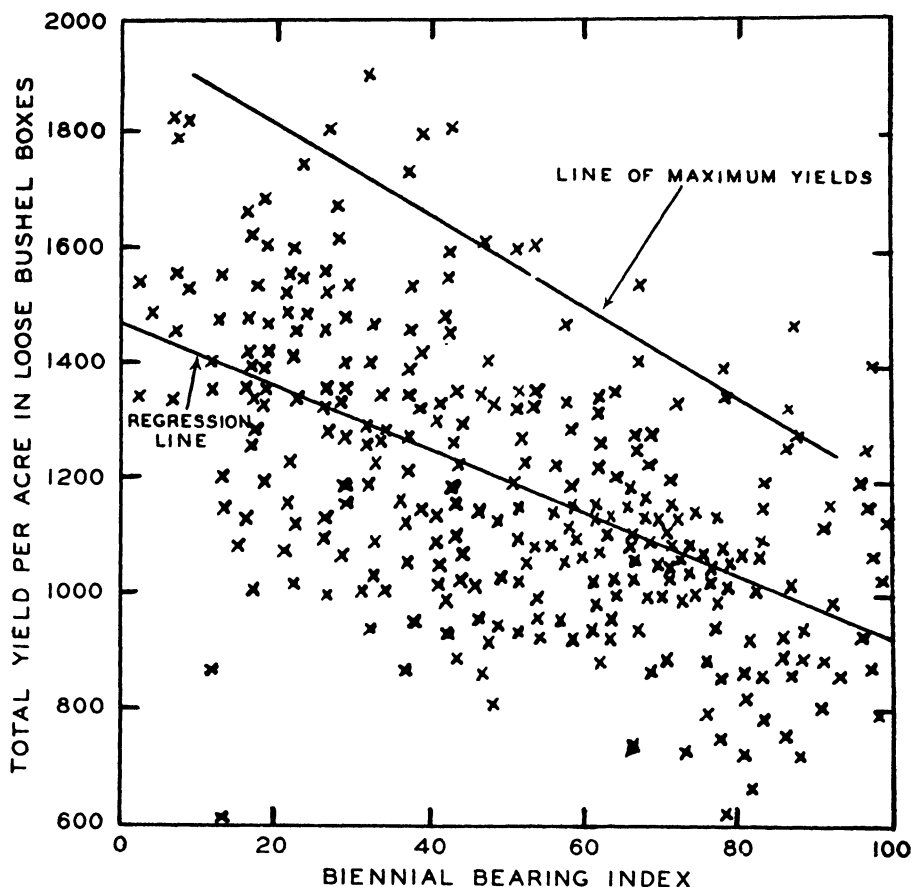


FIGURE 4. Scatter diagram of total yield per acre plotted against biennial bearing index. The yields have been adjusted for differences both in size of tree and in terminal length. $r = -0.526$ (Table 5).

The relationship between profitable yield and tree vigour (as represented by terminal length) can be explained largely by the effect of vigour on the percentage of "non-profitable" fruits. An examination of the field data has revealed that with increasing vigour there was at first little effect on the percentage of non-profitable fruits. When the terminals reached 25 to 30 cm. in length, however, there were sufficient oversized and poorly coloured fruits (both non-profitable) to offset the increase in total yield, and beyond that point increasing vigour was accompanied by an increase in non-profitable yield greater than the increase in total yield. The optimum terminal length appeared to depend to some extent on the degree of tree crowding: if the trees were thick in the centres and the limbs from neighbouring trees were crowding together, 25 cm. appeared to be better than 30 cm.; but if the trees were well opened up and well separated, the reverse appeared to hold true.

Regressions of Yield

The rectilinear regressions of yield on the three factors size of tree, tree vigour and biennial bearing were determined, these factors being represented by the trunk-ground ratio, terminal length, and biennial bearing index, respectively. The determinations were made in two ways: (1) from the slopes of the lines of regression of yield on the three factors; (2) from the slopes of the lines of maximum yield. The more pertinent results are summarized in Table 6. In each case, the slope of the line is expressed in terms of the amount of change in yield per unit change in the factor concerned. For example, the simple regression of total yield per acre on the trunk-ground ratio was + 1987; which means that for each change of 0.1 in the trunk-ground ratio, the average yield per acre changed by 199 boxes in the same direction. As will be seen from Table 6, the lines of maximum yield had greater slopes than the regression lines. This is no doubt due in part to the fact that the slope of the regression line is somewhat less than that of the general trend of the distribution. It will also be noted that the regressions are higher for total yield than for profitable yield.

TABLE 6.—COEFFICIENTS OF REGRESSION OF YIELD PER ACRE ON TRUNK-GROUND RATIO, TERMINAL LENGTH AND BIENNIAL BEARING INDEX

Type of line used	No. of factors eliminated	Regression of yield on		
		Trunk-ground ratio	Terminal length	Biennial bearing index
		boxes	boxes	boxes
A. <i>Total yield per acre</i>				
Regression line	none	+1987	+14.4	-516
Regression line	2*	+1764	+16.0	-535
Maximum yield line	none	+3300	+50.0	-933
B. <i>Profitable yield per acre</i>				
Regression line	none	+1354	—†	-387
Regression line	2*	+1269	—†	-397
Maximum yield line	none	+2583	35.0‡	-514

* When two factors were eliminated, this means that the regression coefficient represents the trend when the other two factors were held constant.

† Correlation too low to justify calculating the regression.

‡ + 35.0 below a terminal length of 27.5 cm., and - 35.0 above 27.5 cm.

The regression coefficients shown in Table 6 do not represent the average effects of the three factors on yield; nor can those for any one factor be compared directly with those for the other factors. In order to convert the data into figures that would have a more direct practical application, the change in yield per *average* deviation of each factor from the optimum was calculated. For this purpose, the optima were considered to be a trunk-ground ratio of 0.37 and up, a terminal length of 27.5 cm., and a biennial bearing index of zero. With trees 30 X 30 feet apart on the square, a trunk-ground ratio of 0.37 is represented by a trunk diameter of about 14 inches. The figures thus obtained for profitable yield are indicated in Table 7.

If it can be assumed that the relationships found between the three factors and yield represent actual effects, either direct or indirect, then the data of Table 7 may be considered to provide a suitable basis for comparing these effects. In the case of terminal length, the figures given will of course

TABLE 7.—AVERAGE LOSS OF PROFITABLE YIELD PER ACRE, ATTRIBUTABLE TO TRUNK-GROUND RATIO, TERMINAL LENGTH AND BIENNIAL BEARING INDEX

Line used as basis	No. of factors eliminated	Loss of yield attributable to		
		Trunk-ground ratio	Terminal length	Biennial bearing index
Regression line	none	boxes 55	boxes —	boxes 187
Regression line	2	52	—	192
Maximum yield line	none	105	110	248
Average deviation of factor from Optimum		0.0408	3.150	0.4825

refer not to any direct effect of terminal length itself on yield, but rather to the effect of all those conditions that are associated with terminal length; that is, what is commonly called tree vigour. It will be noted that the average losses attributable to biennial bearing have been much greater than those attributable to the other two factors.

Distance of Planting

The trees were divided into four groups, in accordance with their distance apart of planting, and a number of different procedures were tried for evaluating the yield differences between these groups. Only two of the groups contained sufficient trees for reliable comparison: (1) trees occupying 780 to 840 square feet of space; (2) trees occupying 900 square feet of space. By all methods of comparison, the yields were somewhat higher in the first of these two groups than in the second. Although the differences were not always "significant" (odds 19 : 1 or higher), they were quite consistent. The conclusion appeared justified, therefore, that under the conditions of this investigation the trees occupying 780 to 840 square feet of space tended to bear more fruit per acre than did those occupying 900 square feet. Some of the averages that were compared are shown in Table 8. It will be noted that successive adjustments increased the averages. This was caused by adjusting to the optimum value rather than to the mean of each factor.

TABLE 8.—AVERAGE YIELDS PER ACRE IN DISTANCE-OF-PLANTING GROUPS

	Area occupied per tree	
	780-840 sq. ft.	900 sq. ft.
No. of trees in group	95	186
A. Total yield per acre		
Unadjusted	1228	1050 (IIS)*
Adjusted for trunk-ground ratio	1261	1179 (NS)
Adjusted for all three factors	1525	1435 (S)
B. Profitable yield per acre		
Unadjusted	1051	920 (S)
Adjusted for trunk-ground ratio	1091	1022 (NS)

* These letters indicate the significance of the difference between each pair of means:

NS—Non-significant, with odds less than 19 : 1.

S—Significant, with odds between 19 : 1 and 99 : 1.

HS—Highly significant, with odds greater than 99 : 1.

The higher yields obtained with the closer planting appear to be associated in part with a greater size of tree per unit area of ground occupied. The trunk-ground ratio was distinctly higher, on the average, with the "780-840" group; and observation indicated that the tops of the trees in this group occupied the orchard space more fully than they did in the "900" group. With the older trees, this difference was not so obvious. It appears that the more closely planted trees come into full production per acre the sooner, but that they also become too crowded for maximum production the sooner. The findings of this investigation, therefore, cannot be applied indiscriminately to other groups of trees either in the Okanagan Valley or elsewhere.

Locality

Comparisons between localities were made in the same manner as between distances of planting. No detailed report on the results obtained will be made at this time. It will be considered sufficient to record that no differences between districts were found that could not be attributed to differences in size of tree, vigour of tree, and biennial bearing. In other words, there was no evidence to indicate either an increase or a decrease in the potential yield per acre of the McIntosh trees as they were located progressively farther north from Penticton to Oyama.

DISCUSSION

In the opinion of the author, the most important finding reported in this paper is the marked effect of biennial bearing on average tree yield. Because of this effect, and because of the prevalence of biennial bearing, the losses of yield from this cause constitute a serious problem in the Okanagan Valley. Another finding of value is that under the conditions of this investigation the optimum degree of vigour of McIntosh trees is indicated by about 25 to 30 cm. (10 to 12 inches) of average terminal growth. This of course does not necessarily apply to other varieties or to other districts. The discovery that even in mature orchards the more closely planted trees have borne the heaviest crops of profitable fruit per acre indicates that wide planting may not be essential to profitable apple production; however, further study is required before it can be concluded that the planting distance recommended for the Okanagan should be reduced below 30 × 30 feet on the square.

SUMMARY

In 1937, McIntosh trees were selected for study in groups of 5 or less, in grower-owned orchards from Penticton to Oyama in the Okanagan Valley. All trees were mature or nearly so, and most of them were surrounded by other trees of the same size and variety. Final statistical analyses were made on 290 selected trees.

For six years (1937-42), records were taken on trunk circumference, terminal length, total yield, and "profitable" yield; and twig weights were determined for two years (1939-40). The profitable yield consisted of fruits between the sizes of $2\frac{1}{4}$ and $3\frac{1}{8}$ inches, and with a solid red colour of at least 20%. From these records were calculated the annual increase in trunk circumference, the trunk-ground ratio (a measure of tree size per

unit of ground space occupied), and the biennial bearing index (a measure of the degree of biennial bearing). The tree yields were adjusted individually for differences in trunk-ground ratio, terminal length, and biennial bearing index. Studies were made primarily by means of correlation, regression, covariance, and scatter diagrams.

Biennial bearing was found to have a marked effect on tree growth. The year of high yield proved to be the year of small increase in trunk circumference, long terminal length, and small terminal diameter. The inter-annual differences were greatest with yield, and progressively less with trunk increase, terminal length, and twig diameter. As a result of these relationships, it was found necessary to use at least two-year averages in studying factorial effects on average yield.

The correlations among the two-or-more-year averages indicated the following trends: (1) The larger the tree, the greater were the total yield and the profitable yield per acre. (2) The longer the terminals, the greater was the total yield but not the profitable yield. (3) The greater the degree of biennial bearing, the less were the total yield and profitable yield. This last effect was the most marked of the three. Biennial bearing appeared to be more closely associated with meteorological conditions than with lack of tree vigour.

The factorial optima determined from the scatter diagrams were as follows: trunk diameter 14 inches or larger (with trees planted 30×30 feet apart on the square), terminal length 25 to 30 cm., and biennial bearing zero (i.e. 100% annual bearing). The average losses of yield resulting from deviations of the three major factors from their optima were much the greatest with biennial bearing.

The trees occupying less than 900 square feet per tree produced higher yields per acre, both of total and of profitable fruit, than did those occupying 900 or more square feet. No differences were found among districts that could not be attributed to differences in the three major factors studied.

ACKNOWLEDGMENTS

The writer wishes to express his appreciation to Dr. E. L. Overholser of the State College of Washington and to Mr. R. C. Palmer of the Dominion Experimental Station at Summerland, for assistance and suggestions made throughout the course of this investigation; to Dr. H. R. McLarty of the Dominion Laboratory of Plant Pathology at Summerland, for suggestions leading toward the initiation of the investigation and for reading the manuscript; to Mr. J. E. Britton of the Dominion Experimental Station at Summerland, for reading the manuscript; to Mr. B. Hoy of the Provincial Department of Agriculture, for permission to locate groups of trees in his fertilizer plots; to Mr. R. P. Murray, Mr. J. Tait, and Mr. H. H. Evans, of the British Columbia Department of Agriculture, for assistance in selecting the McIntosh trees; to Mr. S. D. Dyson and Dr. A. T. Knight, for assistance in the field work; and to all those growers who co-operated so fully in the furtherance of the investigation.

REFERENCES

1. AUCHTER, E. C. and A. L. SCHRADER. Possibilities of affecting biennial bearing in York Imperial apples in the Cumberland-Shenandoah Valley. *Proc. Amer. Soc. Hort. Sci.* 29 : 62-70. 1932.
2. BRADFORD, F. C. Nitrogen-carrying fertilizers and the bearing habits of mature apple trees. *Michigan Agr. Exp. Sta. Spec. Bull.* 127. 1924.
3. BRITISH COLUMBIA DEPARTMENT OF AGRICULTURE LEAFLETS, showing numbers of apple trees in 1940 and average yields from 1937 to 1940. 1941.
4. DICKSON, G. H. A biennial bearing record of an unproductive Baldwin block. *Sci. Agr.* 19 : 583-585. 1939.
5. DORSEY, M. J. Some studies on the fruiting habit of the York Imperial apple. *Proc. Amer. Soc. Hort. Sci.* 22 : 172-189. 1925.
6. GOULDEN, C. H. *Methods of statistical analysis.* John Wiley and Sons, Inc., New York. 1939.
7. HARLEY, C. P., M. P. MASURE and J. R. MAGNESS. Effects of leaf area, nitrate of soda, and soil moisture on fruit bud formation in the Delicious apple. *Proc. Amer. Soc. Hort. Sci.* 29 : 193-198. 1932.
8. HARLEY, C. P., J. R. MAGNESS, M. P. MASURE, L. A. FLETCHER and E. S. DEGMAN. Investigations on the cause and control of biennial bearing of apple trees. *U.S. Dept. Agr. Tech. Bull.* 792. 1942.
9. HOBLYN, T. N., N. H. GRUBB, A. C. PAINTER and B. L. WATES. Studies in biennial bearing. I. *Jour. Pom. Hort. Sci.* 14 : 39-76. 1936.
10. HOOKER, H. D. Annual and biennial bearing in York apples. *Missouri Agr. Exp. Sta. Res. Bull.* 75. 1925.
11. OVERHOLSER, E. L., F. L. OVERLEY and L. M. BARNHILL. Correlations on trunk circumference increase and length of terminal growth with yield of apples. *Proc. Amer. Soc. Hort. Sci.* 35 : 263-268. 1937.
12. OVERHOLSER, E. L., F. L. OVERLEY and J. C. WILCOX. Some correlations between growth and yield of the apple in Central Washington. *Proc. Amer. Soc. Hort. Sci.* 39 : 11-15. 1941.
13. ROBERTS, R. H. Off-year apple bearing and apple spur growth. *Jour. Pom. Hort. Sci.* 2 : 16-37. 1920.
14. ROBERTS, R. H. Annual bearing of Snow and McIntosh. *Wisconsin Agr. Exp. Sta. Spec. Bull.* September, 1941.
15. SNEDECOR, G. W. *Statistical methods.* Collegiate Press Inc., Ames, Iowa. 1938.
16. WALLACE, T. and G. T. SPINKS. A long period field experiment on the manuring of apple trees. *Jour. Pom. Hort. Sci.* 18 : 182-192. 1940.
17. WILCOX, J. C. Field studies of apple tree growth and fruiting. I. Sampling and measuring terminal shoots. *Sci. Agr.* 17 : 563-572. 1937.
18. WILCOX, J. C. Field studies of apple tree growth and fruiting. II. Correlations between growth and fruiting. *Sci. Agr.* 17 : 573-586. 1937.
19. WILCOX, J. C. Field studies of apple tree growth and fruiting. III. Some observations on the measurement of tree vigour. *Sci. Agr.* 17 : 657-669. 1937.
20. WILCOX, J. C. Adjusting apple yields for differences in size of tree. *Sci. Agr.* 21 : 139-148. 1940.

APPENDIX

TABLE 9.—“SUMMARY” DATA FROM MCINTOSH TREES

1	2	3	4	5	6	7	8	9	10	11	12	13
Plot no.*	Tree no.	Years averaged	A†	B†	C†	D†	Total yield‡, adjusted for				Profitable yield‡, adjusted for	
							O†	A†	AC†	ACD†	O†	A†
							boxes	boxes	boxes	boxes	boxes	boxes
				cm.	cm.							
P2	2-1	1938-41	.23	1.44	23.2	55	975	1275	1300	1594	875	1106
	2-3	1938-41	.29	1.87	25.5	90	1124	1318	1311	1792	1095	1245
	2-4	1938-41	.37	2.55	25.8	90	1252	1305	1294	1775	1171	1212
	3-1	1938-41	.23	2.65	37.8	79	771	1071	894	1317	721	952
	3-3	1938-41	.27	2.05	28.2	38	938	1167	1123	1326	866	1043
P3	6-1	1938-41	.29	2.47	29.6	18	1082	1276	1212	1308	1032	1182
	6-4	1938-41	.32	2.35	29.2	66	634	775	717	1070	590	799
	7-1	1938-41	.30	2.22	26.5	21	985	1161	1140	1252	930	1066
	7-3	1938-41	.31	2.85	26.9	69	759	918	892	1261	725	847
	7-4	1938-41	.27	2.52	33.7	66	1037	1266	1146	1199	962	1139
P4	10-1	1938-41	.30	2.67	27.9	86	856	1032	992	1452	798	934
	10-3	1938-41	.32	2.22	25.6	66	833	974	966	1319	799	1008
	10-4	1938-41	.27	2.27	28.7	54	914	1143	1092	1381	839	1016
	11-1	1938-41	.30	2.30	28.7	70	895	1071	1020	1394	837	973
	11-3	1938-41	.30	2.65	29.4	71	863	1039	978	1358	820	956
P1	14-1	1938-41	.26	2.50	30.6	83	616	862	785	1229	592	782
	14-3	1938-41	.25	3.37	25.2	41	622	886	883	1103	572	776
	14-4	1939-41	.31	3.30	30.9	84	1056	1215	1133	1583	992	1114
P9	A	1939-42	.39	3.60	31.5	39	1830	1848	1758	1966	1518	1532
	B	1939-42	.35	3.45	26.5	41	1762	1850	1829	2049	1491	1559
	C	1939-42	.37	3.70	30.5	47	1933	1986	1910	2161	1592	1633
	D	1939-42	.34	3.62	25.4	26	1462	1568	1562	1700	1298	1379
P10	D	1939-42	.35	3.32	32.3	35	1862	1950	1849	2036	1463	1531
P5	A	1939-42	.46	3.17	42.9	33	1429	1323	1075	1252	913	832
	B	1939-42	.47	2.17	38.0	4	1667	1543	1363	1384	1081	986
	C	1939-42	.54	3.02	38.1	16	1680	1434	1253	1339	866	676
	D	1939-42	.55	3.17	38.4	22	1982	1718	1533	1615	1353	1149
	E	1939-42	.51	3.20	36.2	22	1562	1368	1213	1331	1221	1071
P7	B	1939-42	.46	2.30	23.4	42	1365	1259	1281	1505	1116	1035
	D	1939-42	.37	2.32	26.7	66	1036	1089	1065	1418	876	917
	E	1939-42	.38	2.75	27.8	61	986	1021	993	1310	829	856
P6	A	1939-42	.32	1.87	29.6	41	951	1092	1028	1248	786	995
	B	1939-42	.32	2.45	27.5	66	915	1056	1021	1374	786	995
	C	1939-42	.44	2.22	23.3	45	956	886	910	1151	850	796
	D	1939-42	.45	1.82	26.4	32	1084	996	977	1148	930	862
S12	A	1939-42	.32	1.37	20.7	98	587	728	787	1312	514	723
	B	1939-42	.37	2.15	20.3	90	781	834	899	1380	714	755
	C	1939-42	.36	1.77	17.6	94	623	693	795	1298	538	595
	D	1939-42	.33	1.87	23.3	95	732	856	880	1389	642	737
	E	1939-42	.31	1.67	14.7	91	574	733	876	1363	508	630

* Plots arranged in table according to their position in each district.

† A—Trunk-ground ratio.

B—Increase in trunk circumference.

C—Terminal length.

D—Biennial bearing index.

O—No adjustment.

‡ All yields are expressed in terms of loose bushel boxes per acre.

APPENDIX—Continued

TABLE 9.—“SUMMARY” DATA FROM MCINTOSH TREES—*Continued*

1	2	3	4	5	6	7	8	9	10	11	12	13
Plot no.*	Tree no.	Years averaged	A†	B†	C†	D†	Total yield‡, adjusted for				Profitable yield‡, adjusted for	
							O†	A†	AC†	ACD†	O†	A†
							boxes	boxes	boxes	boxes	boxes	boxes
S10	A	1939-42	.33	2.70	27.1	71	628	752	723	1103	592	787
	B	1939-42	.38	2.70	24.2	77	698	733	744	1156	680	707
	C	1939-42	.38	2.70	22.8	76	514	549	579	985	488	515
	D	1939-42	.39	3.80	29.3	38	636	654	595	798	566	580
	E	1939-42	.50	3.50	27.6	47	1072	896	860	1111	1002	866
T2	A	1939-42	.40	2.45	21.1	100	793	793	847	1382	678	678
	B	1939-42	.47	2.92	31.8	100	1217	1093	999	1534	1001	906
	D	1939-42	.58	3.65	28.9	100	1441	1124	1070	1605	1208	963
	E	1939-42	.61	3.72	31.2	100	1367	997	911	1446	1108	822
T3	A	1939-42	.45	3.32	34.8	76	1238	1150	1014	1420	1077	1009
	B	1939-42	.50	3.62	30.8	85	1345	1169	1089	1544	1216	1080
	D	1939-42	.40	3.25	34.2	83	1335	1335	1208	1652	1140	1140
	E	1939-42	.55	3.47	29.9	97	1551	1287	1219	1738	1313	1109
T6	A	1939-42	.29	2.76	20.6	97	1158	1352	1413	1932	1021	1171
	B	1939-42	.35	3.72	28.9	90	1301	1389	1335	1816	1117	1185
	C	1939-42	.27	2.95	30.5	100	1144	1373	1297	1932	967	1144
	D	1939-42	.22	3.00	32.5	95	960	1277	1173	1682	844	1089
	E	1939-42	.23	2.99	33.2	98	953	1253	1139	1664	839	1068
T7	A	1939-42	.28	3.07	30.1	70	1169	1381	1310	1684	979	1142
	B	1939-42	.27	2.77	24.9	75	1107	1336	1337	1738	930	1107
	C	1939-42	.25	2.85	29.0	80	1169	1433	1378	1806	983	1187
	D	1939-42	.28	3.60	31.9	94	1019	1231	1136	1639	855	1018
	E	1939-42	.29	3.70	33.5	97	1099	1293	1175	1694	948	1098
T8	A	1939-42	.38	3.22	31.5	27	1421	1456	1366	1510	1230	1257
	B	1939-42	.41	2.50	30.5	40	1489	1471	1395	1609	1282	1268
	C	1939-42	.43	1.97	25.3	27	1316	1263	1259	1403	1108	1067
	D	1939-42	.44	1.60	27.5	7	1623	1553	1518	1555	1431	1377
T9	A	1939-42	.37	2.52	22.6	58	1211	1264	1297	1607	1124	1165
K1	B15	1938-41	.23	1.95	17.1	53	673	973	1082	1366	610	831
	D15	1938-41	.30	2.35	17.2	46	1083	1259	1367	1613	1016	1152
	H15	1938-41	.30	2.70	20.0	50	1310	1314	1382	1651	1020	1156
K2	S15	1939-42	.31	1.62	17.2	21	1211	1370	1478	1590	1339	1261
	S16	1940-41	.34	2.00	13.0	16	1381	1487	1653	1739	1248	1329
	U15	1938-42	.27	1.92	20.0	36	876	1105	1174	1366	850	1027
	U16	1938-42	.30	2.20	18.0	41	1238	1414	1511	1731	1179	1315
	V15	1938-42	.34	1.98	16.0	20	1216	1322	1446	1553	1141	1222
K6	Z10	1938-42	.25	3.18	23.7	31	1187	1451	1469	1635	1080	1284
	Z11	1938-42	.30	3.22	22.3	29	1254	1430	1467	1622	1120	1256
	AA10	1938-42	.22	2.96	22.2	13	1042	1359	1398	1467	955	1200
K21	DD2	1938-41	.24	2.27	20.3	15	871	1153	1218	1566	744	962
	EE2	1038-41	.30	3.42	21.7	59	956	1132	1178	1494	858	994
	GG2	1938-41	.37	3.62	16.8	64	1476	1190	1304	1642	1041	1218
	HH2	1938-41	.31	3.30	21.1	67	932	1091	1145	1503	841	963
	II2	1938-41	.35	3.72	25.9	70	1024	1112	1100	1474	850	918

* Plots arranged in table according to their position in each district.

† A—Trunk-ground ratio.

B—Increase in trunk circumference.

C—Terminal length.

D—Biennial bearing index.

O—No adjustment.

‡ All yields are expressed in terms of loose bushel boxes per acre.

APPENDIX—Continued

TABLE 9.—“SUMMARY” DATA FROM MCINTOSH TREES—*Continued*

1	2	3	4	5	6	7	8	9	10	11	12	13
Plot no.*	Tree no.	Years averaged	A†	B†	C†	D†	Total yield‡, adjusted for				Profitable yield‡, adjusted for	
							O†	A†	AC†	ACD†	O†	A†
				cm.	cm.		boxes	boxes	boxes	boxes	boxes	boxes
K7	A	1938-41	.33	3.95	26.0	41	941	1065	1051	1271	851	946
	B	1938-41	.29	2.90	25.1	55	723	917	916	1210	686	836
	C	1939-42	.34	2.00	20.5	73	953	1059	1121	1511	919	1000
	D	1938-42	.34	3.12	30.6	72	1094	1200	1123	1508	1012	1093
	E	1938-41	.33	4.20	28.0	44	1037	1161	1119	1355	920	1015
K9	A	1939-42	.40	2.07	14.7	68	949	949	1092	1456	908	908
	B	1939-42	.29	1.52	20.8	72	802	996	1054	1439	733	883
	C	1939-42	.45	2.15	25.2	84	908	820	817	1267	845	777
	D	1939-42	.38	2.17	20.8	79	973	1008	1066	1489	914	941
	E	1939-42	.39	2.10	23.7	78	830	848	866	1283	782	796
K27	A	1939-42	.39	1.67	18.4	81	839	857	948	1382	796	810
	B	1939-42	.39	2.45	16.6	57	810	828	944	1249	761	775
	C	1939-42	.33	2.07	16.4	73	740	864	983	1373	726	821
	D	1939-42	.36	1.77	14.1	86	669	739	890	1350	642	696
	E	1939-42	.39	2.00	15.8	84	600	618	745	1195	579	593
K16	A	1939-42	.31	2.30	22.9	64	945	1104	1133	1475	878	1000
	B	1939-42	.37	2.22	23.5	69	1084	1137	1158	1527	1005	1046
	C	1939-42	.36	2.65	22.8	76	1017	1087	1117	1523	936	990
	D	1939-42	.37	2.72	24.2	64	1278	1331	1342	1684	1180	1221
	E	1939-42	.32	2.32	29.0	65	1073	1214	1159	1507	945	1154
K10	A	1938-41	.36	1.82	22.1	17	1455	1525	1565	1656	1350	1404
	B	1938-41	.30	1.97	23.6	54	762	938	957	1246	692	828
	C	1938-41	.32	2.20	23.5	31	1043	1184	1205	1371	929	1138
	D	1938-41	.39	3.80	22.7	47	949	967	999	1250	882	896
K54	A	1939-42	.34	1.47	24.2	16	1481	1587	1598	1684	1335	1416
	B	1939-42	.36	2.15	26.1	14	1298	1368	1353	1428	1118	1172
	C	1939-42	.33	2.62	27.2	23	1432	1556	1526	1649	824	919
	D	1939-42	.35	1.90	27.5	18	1312	1400	1365	1461	944	1012
	E	1939-42	.37	2.87	25.6	13	1138	1191	1183	1252	991	1032
K11	A	1939-42	.23	2.50	23.7	46	817	1117	1135	1381	690	921
	B	1939-42	.26	3.35	27.7	55	1113	1359	1322	1616	839	1029
	E	1939-42	.22	2.27	30.3	40	969	1286	1213	1427	799	1044
K12	A	1939-42	.33	2.22	29.3	43	1393	1517	1458	1688	1169	1264
	B	1939-42	.27	2.55	25.1	52	930	1159	1158	1436	757	934
	C	1939-42	.32	2.25	26.6	22	1223	1364	1342	1460	1048	1257
	D	1939-42	.27	1.77	20.5	41	1023	1252	1314	1534	884	1061
	E	1939-42	.26	2.10	25.7	56	1210	1456	1446	1746	1017	1207
K13	A	1939-42	.30	2.42	25.7	51	1066	1242	1232	1505	915	1051
	B	1939-42	.30	1.87	23.9	52	1169	1345	1360	1638	1030	1166
	C	1939-42	.32	2.55	28.2	57	1006	1147	1103	1408	860	1069
	D	1939-42	.33	1.90	26.8	55	1253	1377	1352	1646	1127	1222
	E	1939-42	.30	2.35	24.5	45	1343	1519	1526	1767	1150	1286

* Plots arranged in table according to their position in each district.

† A—Trunk-ground ratio.

B—Increase in trunk circumference.

C—Terminal length.

D—Biennial bearing index.

O—No adjustment.

‡ All yields are expressed in terms of loose bushel boxes per acre.

APPENDIX—Continued

TABLE 9.—“SUMMARY” DATA FROM MCINTOSH TREES—*Continued*

1	2	3	4	5	6	7	8	9	10	11	12	13
Plot no.*	Tree no.	Years averaged	A†	B†	C†	D†	Total yield‡, adjusted for				Profitable yield‡, adjusted for	
							O†	A†	AC†	ACD†	O†	A†
				cm.	cm.		boxes	boxes	boxes	boxes	boxes	boxes
K14	A	1939-42	.28	2.40	24.4	54	1132	1344	1352	1641	1018	1181
	B	1939-42	.25	1.80	27.7	53	999	1263	1226	1510	842	1046
	C	1939-42	.31	1.92	19.0	67	975	1134	1217	1575	890	1012
	D	1939-42	.30	2.45	26.8	43	1090	1266	1241	1471	948	1084
	E	1939-42	.25	2.20	28.1	39	1139	1403	1360	1568	988	1192
K15	C	1939-42	.24	1.67	26.8	51	732	1014	989	1262	642	860
	D	1939-42	.28	1.22	23.8	45	751	963	980	1221	654	817
	E	1939-42	.25	1.37	23.6	46	503	767	786	1032	436	640
K46	B	1938-42	.22	2.58	29.2	48	659	967	918	1175	646	891
	C	1938-42	.27	2.46	27.3	35	988	1217	1185	1372	781	958
	E	1938-42	.29	3.76	27.9	59	1031	1225	1185	1501	785	935
K51	A	1939-42	.36	2.80	23.6	60	993	1063	1082	1403	848	902
	B	1939-42	.28	3.05	27.5	71	811	1023	988	1368	636	799
	E	1939-42	.33	3.07	29.1	52	1041	1165	1108	1386	885	980
K22	A	1939-42	.35	2.30	25.2	67	1110	1198	1195	1553	1021	1089
	B	1939-42	.30	2.47	24.7	67	1096	1272	1276	1634	1021	1157
	C	1939-42	.29	2.20	20.2	67	1269	1463	1529	1887	1185	1335
	D	1939-42	.25	2.30	21.6	67	1110	1374	1421	1779	1069	1273
	E	1939-42	.27	2.27	27.0	70	1069	1298	1270	1644	999	1176
K25	B	1938-42	.37	2.78	25.7	38	1480	1533	1523	1726	1309	1350
	C	1938-42	.34	2.60	30.7	37	1430	1536	1457	1655	1253	1334
K24	A	1939-42	.34	1.85	25.3	27	1307	1413	1409	1553	1165	1246
	B	1939-42	.42	2.37	25.9	87	1538	1503	1491	1956	1376	1349
	E	1939-42	.36	2.62	25.3	54	1543	1613	1609	1898	1433	1487
K49	B	1938-42	.29	4.18	34.8	32	1213	1407	1271	1442	818	968
	C	1938-42	.30	3.60	29.8	40	1139	1315	1249	1463	1115	1026
	D	1938-42	.23	3.04	26.7	34	1028	1328	1304	1486	815	1046
K8	A	1940-41	.34	3.40	18.0	30	1440	1546	1643	1803	1230	1311
	B	1940-41	.35	3.44	25.3	40	1350	1438	1434	1648	1103	1171
	C	1939-42	.32	2.97	27.5	39	1704	1845	1810	2018	1487	1696
	D	1940-41	.36	3.00	27.9	28	1619	1689	1649	1799	1431	1395
	E	1940-41	.34	2.90	21.6	27	1676	1782	1829	1973	1511	1592
K48	A	1939-42	.26	3.60	26.4	65	1151	1397	1378	1726	995	1185
	B	1938-42	.25	4.02	32.1	49	1209	1473	1375	1621	982	1186
	C	1938-42	.28	3.92	33.3	42	1236	1448	1333	1557	1049	1212
	D	1938-42	.24	3.70	34.6	57	1008	1290	1157	1462	863	1081
	E	1939-42	.30	3.25	26.3	77	1246	1422	1404	1816	988	1124
B29	A	1938-42	.27	4.06	23.1	28	808	1037	1063	1213	761	938
	B	1938-42	.25	4.32	23.6	31	1133	1309	1328	1494	1079	1215
	C	1938-42	.20	2.38	11.5	76	532	875	1062	1468	477	749
	D	1938-42	.26	4.22	27.3	41	977	1223	1191	1411	931	112
	E	1938-42	.23	3.96	28.5	50	658	958	910	1178	631	826

* Plots arranged in table according to their position in each district.

† A—Trunk-ground ratio.

B—Increase in trunk circumference.

C—Terminal length.

D—Biennial bearing index.

O—No adjustment.

‡ All yields are expressed in terms of loose bushel boxes per acre.

APPENDIX—Continued

TABLE 9.—“SUMMARY” DATA FROM MCINTOSH TREES—Continued

1	2	3	4	5	6	7	8	9	10	11	12	13
Plot no.*	Tree no.	Years averaged	A†	B†	C†	D†	Total yield‡, adjusted for				Profitable yield‡ adjusted for	
							O†	A†	AC†	ACD†	O†	A†
				cm.	cm.		boxes	boxes	boxes	boxes	boxes	boxes
B30	A	1938-42	.28	5.24	34.4	34	944	1156	1026	1208	816	979
	B	1938-42	.30	4.70	29.4	27	1050	1226	1165	1309	935	1071
	C	1938-42	.27	4.74	27.5	41	910	1139	1104	1324	769	946
	D	1938-42	.23	5.06	35.6	54	823	1123	976	1265	641	872
	E	1938-42	.28	5.16	35.4	42	996	1208	1064	1288	859	1022
B31	A	1938-42	.27	4.18	24.4	43	891	1120	1128	1358	836	1013
	B	1938-42	.29	4.54	24.1	41	1099	1293	1305	1525	990	1140
	D	1938-42	.23	4.88	32.1	53	784	1084	986	1270	709	940
B32	A	1938-42	.21	3.22	21.6	46	581	916	963	1209	537	795
	C	1938-42	.30	4.92	31.3	46	1040	1216	1129	1375	911	1047
	D	1938-42	.25	4.20	27.6	57	843	1107	1071	1376	780	984
	E	1938-42	.25	5.50	29.2	56	871	1135	1077	1377	759	963
B1	A	1939-42	.39	2.57	24.6	73	1151	1169	1175	1565	958	972
	B	1939-42	.41	2.80	26.8	59	1175	1157	1132	1448	988	974
	C	1939-42	.43	2.43	22.6	62	1094	1059	1092	1424	921	894
	D	1939-42	.37	2.17	19.4	65	1060	1113	1190	1538	927	968
	E	1939-42	.39	2.00	19.4	65	945	963	1040	1388	855	869
B34	A	1939-42	.38	2.17	23.8	75	1091	1126	1143	1544	982	1009
	B	1939-42	.44	2.92	27.5	78	1086	1016	981	1398	892	843
	C	1939-42	.40	2.85	25.3	83	1079	1079	1072	1516	952	952
	D	1939-42	.39	2.87	26.2	85	1068	1083	1066	1521	939	953
	E	1939-42	.39	2.92	26.9	94	1031	1049	1023	1526	878	892
B33	B	1939-42	.36	2.77	15.5	37	1149	1219	1350	1548	1072	1126
	C	1939-42	.40	2.67	19.2	60	1277	1277	1357	1678	1205	1205
	D	1939-42	.38	2.35	21.1	55	1531	1566	1620	1914	1141	1468
	E	1939-42	.38	3.32	23.3	42	1566	1601	1625	1849	1405	1432
B38	A	1938-41	.39	2.75	20.2	40	1089	1107	1173	1387	1272	1069
	B	1938-41	.39	2.75	18.0	63	1200	1218	1315	1652	1092	1106
	C	1938-41	.41	2.25	22.7	71	1229	1211	1243	1623	1111	1097
	D	1938-41	.44	3.10	20.2	19	1445	1375	1441	1543	1351	1297
	E	1938-41	.49	3.37	15.3	63	1047	888	1022	1359	977	855
B36	A	1939-42	.39	2.07	26.8	85	866	884	859	1314	832	846
	B	1939-42	.40	2.02	25.1	90	942	942	941	1422	902	902
	C	1939-42	.43	1.92	23.4	88	894	841	863	1334	845	804
	D	1939-42	.42	2.55	25.5	87	957	922	915	1580	929	902
	E	1939-42	.38	2.05	29.7	88	776	811	746	1217	740	767
B37	A	1939-42	.38	2.65	26.1	87	745	780	765	1230	708	735
	B	1939-42	.37	2.57	24.5	85	806	859	866	1321	769	810
	C	1939-42	.40	2.80	29.1	83	715	715	658	1102	661	661
	D	1939-42	.37	2.50	29.5	45	1059	1112	1050	1291	999	1040
	E	1939-42	.38	3.17	31.1	61	980	1015	931	1257	920	947
G42	A	1939-42	.35	2.60	24.5	16	1580	1668	1675	1777	1368	1436
	B	1939-42	.36	2.92	27.1	10	1755	1825	1796	1849	1410	1464
	C	1939-42	.35	3.05	24.4	25	1369	1457	1465	1599	1145	1213
	D	1939-42	.30	2.77	27.3	42	1119	1295	1263	1487	927	1063
	E	1939-42	.33	2.35	25.3	23	1641	1765	1761	1884	1369	1464

* Plots arranged in table according to their position in each district.

† A—Trunk-ground ratio.

B—Increase in trunk circumference.

C—Terminal length.

D—Biennial bearing index.

O—No adjustment.

‡ All yields are expressed in terms of loose bushel boxes per acre.

APPENDIX—Continued

TABLE 9.—“SUMMARY” DATA FROM MCINTOSH TREES—*Continued*

1	2	3	4	5	6	7	8	9	10	11	12	13
Plot no.*	Tree no.	Years averaged	A†	B†	C†	D†	Total yield‡, adjusted for				Profitable yield‡, adjusted for	
							O†	A†	AC†	ACD†	O†	A†
							boxes	boxes	boxes	boxes	boxes	boxes
G50	A	1939-42	.47	2.82	27.3	80	957	833	801	1229	810	715
	B	1939-42	.36	3.10	26.0	65	1076	1146	1132	1480	894	948
	C	1939-42	.39	2.90	27.6	67	1132	1150	1114	1472	957	971
	D	1939-42	.47	3.27	28.4	71	1188	1064	1017	1397	950	855
	E	1939-42	.46	3.10	23.9	76	1013	907	922	1328	839	758
G26	A	1939-42	.36	2.37	22.7	17	1211	1281	1313	1404	1055	1109
	B	1939-42	.31	1.55	26.6	23	1447	1606	1584	1707	1170	1292
	C	1939-42	.38	2.52	25.9	7	1792	1827	1815	1815	1484	1511
	D	1939-42	.29	2.12	22.0	19	1174	1368	1410	1512	993	1143
	E	1939-42	.36	1.40	24.8	10	1708	1778	1781	1834	1460	1514
G18	A	1939-42	.40	3.65	27.9	59	957	957	917	1227	727	727
	B	1939-42	.38	3.65	25.9	63	866	901	889	1226	685	712
	C	1939-42	.39	2.92	25.2	59	1149	1167	1164	1480	824	838
	D	1939-42	.40	3.40	22.4	61	1138	1138	1174	1500	842	842
	E	1939-42	.41	3.57	27.2	65	1012	994	964	1312	739	725
G17	A	1939-42	.29	1.77	20.2	74	787	981	1047	1443	722	872
	B	1939-42	.33	2.62	21.5	77	872	996	1044	1456	810	905
	C	1939-42	.24	1.42	20.4	73	751	1033	1097	1487	703	921
	E	1939-42	.33	1.90	16.4	80	781	905	1024	1452	730	825
G19	B	1939-42	.35	2.47	25.1	18	1191	1279	1278	1374	1043	1111
	C	1939-42	.35	2.17	20.0	45	956	1025	1266	1266	782	850
	D	1939-42	.36	2.37	21.2	30	1128	1198	1251	1411	1056	1110
G20	A	1939-42	.31	2.05	22.5	50	1296	1455	1605	1873	1188	1310
	B	1939-42	.32	2.32	24.4	29	1150	1291	1341	1496	1029	1238
	C	1939-42	.35	1.82	22.6	18	1175	1263	1381	1477	1065	1133
	D	1939-42	.34	1.25	18.8	20	1235	1341	1479	1586	1128	1209
	E	1939-42	.31	1.60	13.1	25	775	934	1147	1281	727	849
W2	A	1939-42	.35	2.62	20.5	30	842	930	992	1152	697	765
	B	1939-42	.34	2.25	21.7	34	830	936	982	1164	715	796
	E	1939-42	.32	1.82	16.4	16	1175	1316	1435	1521	1080	1299
W7	A	1939-42	.28	2.42	33.0	15	781	993	882	962	655	818
	B	1939-42	.34	2.00	25.5	18	1018	1124	1117	1213	847	928
	C	1939-42	.29	1.82	24.9	17	895	1089	1090	1181	739	889
	D	1939-42	.33	1.60	24.7	20	914	1038	1042	1149	774	869
	E	1939-42	.31	3.10	32.1	14	578	737	639	714	484	606
W6	B	1939-42	.32	2.32	26.8	75	775	916	891	1292	715	924
	C	1939-42	.29	1.42	19.4	36	660	854	931	1123	636	786
	D	1939-42	.29	1.87	25.2	32	763	957	954	1125	696	846
W5	C	1940-41	.32	1.80	20.6	21	1212	1388	1449	1561	993	1129
	E	1940-41	.32	1.50	16.3	35	994	1135	1255	1442	813	1022

* Plots arranged in table according to their position in each district.

† A—Trunk-ground ratio. B—Increase in trunk circumference.

C—Terminal length. D—Biennial bearing index.

O—No adjustment.

‡ All yields are expressed in terms of loose bushel boxes per acre.

APPENDIX—Concluded

TABLE 9.—“SUMMARY” DATA FROM MCINTOSH TREES—*Concluded*

1	2	3	4	5	6	7	8	9	10	11	12	13
Plot no.*	Tree no.	Years averaged	A†	B†	C†	D†	Total yield‡, adjusted for				Profitable yield‡, adjusted for	
							O†	A†	AC†	ACD†	O†	A†
				cm.	cm.		boxes	boxes	boxes	boxes	boxes	boxes
W9	F	1939-42	.40	3.24	27.9	26	1512	1512	1472	1610	1086	1086
	G	1939-42	.34	2.72	28.3	21	1361	1467	1421	1533	1120	1201
	H	1939-42	.44	3.52	31.2	28	1689	1619	1533	1683	1289	1235
	I	1939-42	.37	2.99	31.7	23	1589	1642	1549	1672	1160	1201
	J	1939-42	.43	3.32	28.8	13	1680	1627	1574	1643	1402	1361
	K	1939-42	.37	2.92	29.3	8	1580	1633	1574	1617	1322	1363
W8	F	1939-42	.34	2.95	25.8	20	1547	1653	1642	1749	1020	1101
	G	1939-42	.39	3.56	29.3	12	1520	1538	1479	1543	1269	1283
	H	1939-42	.33	2.81	24.4	18	1183	1307	1315	1411	1038	1133
	I	1939-42	.38	3.38	28.0	10	1448	1533	1491	1544	1287	1314
	J	1939-42	.30	2.38	26.0	10	1153	1329	1315	1368	999	1135
	K	1939-42	.35	2.98	28.6	2	1468	1556	1506	1517	1248	1316
W10	F	1939-42	.47	1.61	26.1	34	1555	1431	1409	1591	1350	1255
	G	1939-42	.44	1.41	25.5	31	1338	1268	1261	1427	1180	1126
	H	1939-42	.47	1.82	25.1	20	1665	1541	1540	1695	1435	1340
	I	1939-42	.47	1.59	24.5	26	1448	1324	1331	1469	1265	1170
O14	A	1938-42	.36	2.94	24.2	24	968	1039	1048	1177	935	989
	B	1938-42	.35	2.96	24.8	29	1285	1373	1376	1531	1113	1181
	C	1938-42	.40	3.40	22.2	16	1327	1327	1366	1452	1200	1200
	D	1939-42	.39	2.40	20.7	4	1447	1465	1556	1577	1326	1340
	E	1938-42	.39	2.86	23.8	27	1153	1171	1188	1332	1050	1064
O17	A	1939-42	.32	2.62	23.8	75	836	977	994	1395	732	941
	B	1939-42	.36	3.27	24.2	78	980	1050	1061	1478	878	932
	C	1939-42	.37	2.87	25.7	65	875	928	918	1266	788	829
	D	1939-42	.38	2.87	28.5	62	1017	1052	1004	1336	884	911
	E	1939-42	.33	2.60	23.5	81	972	996	1017	1451	775	870
O15	A	1939-42	.27	3.82	35.7	38	799	1028	880	1083	565	742
	B	1939-42	.26	3.25	34.6	27	986	1232	1099	1243	799	989
	C	1939-42	.32	2.57	36.3	28	1126	1267	1111	1261	860	1069
	D	1939-42	.27	2.95	31.3	13	981	1210	1123	1192	829	1006
	E	1939-42	.24	2.85	29.5	37	889	1171	1109	1307	806	1024
O19	A	1938-41	.36	1.60	16.4	73	906	976	1095	1485	761	815
	B	1938-41	.37	1.45	13.7	49	819	872	1028	1200	619	660
	C	1938-41	.35	1.57	13.1	70	871	959	1124	1498	721	789
	D	1938-41	.36	1.67	13.1	70	832	907	1072	1446	698	752
	E	1938-41	.37	1.45	17.0	24	872	925	1036	1164	786	827

* Plots arranged in table according to their position in each district.

† A—Trunk-ground ratio.

B—Increase in trunk circumference.

C—Terminal length.

D—Biennial bearing index.

O—No adjustment.

‡ All yields are expressed in terms of loose bushel boxes per acre.

BOOK REVIEW

THE CATTLE OF BRITAIN. By Frank H. Garner, Cambridge University.
158 pages, 60 figs. Longmans, Green & Co., 215 Victoria St.,
Toronto 1, Ont. 1944. Price \$5.50.

Practically all of the breeds of cattle which have been utilized in developing the cattle industry of Canada had their origin in Great Britain. Since this is the case, it is a matter of special interest to Canadians that a new book *The Cattle of Britain*, by a British authority, has just been published. The author is Frank H. Garner, Lecturer in Agriculture at Cambridge University and for some time Agricultural Organizer in East Suffolk.

This book may well serve in a dual rôle, namely, as a handbook for cattle raisers and as a text-book or reference for animal husbandry students in Colleges or Schools of Agriculture. The subject of cattle production under the conditions prevailing in Great Britain is treated in an essentially practical manner; the best in British practices has been sorted out and the methods discussed in a very readable style.

The forepart of the book is devoted to a historical account of the development of the cattle industry of Great Britain, including some comment on the work of early improvers, the formation of breeds, agricultural shows and other such matters. The importance of cattle raising in the agricultural pattern of Britain is then discussed. A considerable section concerns itself with certain general problems of cattle management, including a consideration of some of the common ailments and pests. Beef cattle, dairy cattle, and dual purpose cattle are each dealt with in turn; the breeds common to Britain are described and methods appropriate to the various types of cattle production are outlined.

The concluding chapter of *The Cattle of Britain* brings us up to date on the effects of the war on the cattle industry of Great Britain. Of special interest is an account of the steps which have been taken to improve the quantity and quality of the milk supply and the effect of the ploughing-up campaign on methods of beef production.

The book carries sixty excellent illustrations displayed on glossy paper. Included is a pen drawing of the Smithfield Show Champion in 1873 (24 cwt. at 4 years of age).

R. D. SINCLAIR.

THE ACID-OXALATE EXTRACTS OF PODZOL AND PODZOLIC SOILS¹

P. G. LAJOIE² AND W. A. DELONG³

Macdonald College, Quebec

The acid ammonium oxalate extraction method of Tamm (9) has been applied to the study of the problems of soil genesis and of the differentiation of podzol, brown forest, and ground-water soils. Thus, Lundblad (7) and Hoon (6) have found marked differences in the amounts of silica and of sesquioxides extracted from the various horizons of soils of the classes mentioned. The procedure is considered to give an approximate measure of the quantities of reactive weathering products in the soil.

It was thought possible that the Tamm procedure might have some usefulness in the differentiation of soil types. The objective of the present investigation was to test this possibility in the case of a number of podzolized soils. Duplicate, in one instance triplicate, profiles of 7 soil types were examined with this end in view. These 7 types have been classified (2) as belonging to the following soil groups: podzols, ill-drained podzols and brown podzolics, with one soil described as transitional between the podzols and the brown podzolics. In the present report this transitional soil has been classed as a brown podzolic for purposes of discussion. Some information on these soils is presented in Table 1. They are more fully described elsewhere (2).

¹ Based on a thesis presented by P. G. Lajoie to the Faculty of Graduate Studies of McGill University in partial fulfilment of the requirements for the degree of Master of Science. Contribution from the Faculty of Agriculture, McGill University, Macdonald College, Que., Canada. Macdonald College Journal Series No. 200 Presented before a meeting of the Soils Group of the Canadian Society of Technical Agriculturists of Toronto, Ontario, June 27-29, 1944.

² Soil Specialist, Experimental Farm Service, Dominion Department of Agriculture, presently stationed at Macdonald College, Quebec.

³ Associate Professor of Chemistry.

TABLE 1.—DESCRIPTION OF SOILS STUDIED

Soil group	Soil type	Dominant parent materials
Podzols	Ascot s. loam (2)* Greensboro loam (2) Greensboro loam, strongly rolling phase (2)	Non-calciferous slates and shales. Slate; impure limestone. Slate; impure limestone.
Poorly-drained podzols	Magog stony loam (2) Brompton stony loam (3)	Non-calciferous slates and shales. Slate; sandstone.
Brown Podzolic	Berkshire loam† (2) Woodbridge loam (2)	Schist. Schist.

* Indicates the number of profiles studied.

† Considered as transitional between the podzols and the brown podzolic soils.

EXPERIMENTAL

In the collection of the podzol samples no attempt was made to separate an A_1 horizon, the profiles of this class examined being practically devoid of this horizon. The horizon designated as A_0 therefore includes all the soil between the litter and the A_2 in the case of the podzol profiles studied.

All analytical determinations were made on air-dry soil passing a 1.0 mm. sieve. The following characteristics were determined: loss on ignition, pH, and the amounts of silicon, iron, aluminium, titanium manganese and phosphorus brought into solution by extraction with the Tamm reagent.

The pH values were determined electrometrically using a glass electrode and a Hellige pH meter at a soil: water ratio of 1 : 2.5. The results for loss in ignition and pH are shown in Table 2.

The acid ammonium oxalate reagent was prepared according to the method of Lundblad (7). The extractions with this reagent were made by placing 5-gram samples of soil in 250 ml. Erlenmeyer flasks containing 100 ml. of the solution and shaking continuously for 30 minutes on a horizontal rotating shaking machine. The mixture was then filtered by

TABLE 2.—MEAN PERCENTAGE VALUES FOR LOSS ON IGNITION AND pH RANGES

Horizon	Podzols		Ill-drained podzols		Brown podzolics	
	Loss on ignition	pH range	Loss on ignition	pH range	Loss on ignition	pH range
A_0	33.4	3.7-4.6	22.7	4.1-6.0	16.7*	4.5-4.9*
A_2	2.7	4.0-4.6	3.5	4.0-6.2	6.0†	4.5-4.6†
B_1	11.0	4.1-4.8	2.0	5.5-6.8	6.4	4.7-5.2
B_2	5.7	4.6-5.1	—	—	4.8	5.0-5.3
C	2.0	4.8-5.9	1.3	5.6-6.9	2.2	5.1-5.8

* Average values for the A_0 horizon of the Berkshire soils and the A horizon of the Woodbridge soils.

† Loss on ignition and pH values for the Berkshire soil only.

suction using a No. 5 Whatman paper, the residue returned to the flask and the extraction repeated. Finally, the residual soil was washed with 25 ml. of the extracting solution. The filtrates and washings were taken to dryness on the steam bath and ignited at 550° C. The ignited residues were dissolved in concentrated hydrochloric acid and the solution taken to dryness to dehydrate the silica. After dissolving the sesquioxides in HCl solution the filtrate was again dehydrated to ensure complete recovery of silica. The total silica was determined gravimetrically. The filtrate and washings from the silica separation were made up to a volume of 200 ml. and suitable aliquots taken for the determination of manganese, titanium, iron and phosphorus. The remainder of the solution was used for the determination of total sesquioxides, that is, of the oxides of iron, aluminium, titanium and phosphorus without manganese. The method used was that of Hillebrand and Lundell (5).

Iron, phosphorus, titanium and manganese were determined colorimetrically, iron by the method of Dyer and McFarlane (3), phosphorus by

that of Dyer and Wrenshall (4), titanium by the procedure of Hillebrand and Lundell (5, p. 456), and manganese by that of Richards (8). Alumina was estimated as the difference between the total sesquioxide minus the sum of the oxides of iron, titanium and phosphorus.

RESULTS AND DISCUSSION

The data obtained for the amounts of silica extractable from these soils by the Tamm reagent are given in Table 3. The podzols and the transitional Berkshire soil showed, as expected, very small amounts of oxalate-soluble silica in the A₂ horizons, with some accumulation of this component in the B horizons, especially in the B₂. The amount of this fraction was low and uniform throughout the profiles of the ill-drained podzols and of the brown podzolic Woodbridge soil.

TABLE 3.—MEAN VALUES FOR EXTRACTABLE SILICA AS PERCENTAGE OF DRY SOIL

Horizon	Podzols	Ill-drained podzols	Transitional (Berkshire)	Brown podzolic (Woodbridge)
A ₀	.03	.03	.05	.08
A ₂	.03	.03	.02	—
B ₁	.16	.03	.08	.04
B ₂	.25	—	.10	.08
C	.10	.04	.09	.07

The molar silica-sesquioxide ratios shown in Table 4, exhibited the expected zig-zag pattern in the podzol profiles, were relatively uniform throughout the profile in the brown podzolic soils, and showed a general increase with depth in the ill-drained podzols. The mean values of these ratios are shown in Table 4. It would appear from these results that these ratios might be used for differentiation at the soil group level but further confirmatory work is desirable.

TABLE 4.—MEAN VALUES OF THE MOLAR SILICA-SESQUIOXIDE RATIOS

Horizon	Podzols		Brown podzolic		Ill-drained podzols	
	$\frac{\text{SiO}_2}{\text{Fe}_2\text{O}_3}$	$\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3}$	$\frac{\text{SiO}_2}{\text{Fe}_2\text{O}_3}$	$\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3}$	$\frac{\text{SiO}_2}{\text{Fe}_2\text{O}_3}$	$\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3}$
A ₀	.11	.16	.19	.23	.12	.10
A ₂	.40	.55	.16*	.17*	.32	.27
B ₁	.18	.15	.16	.14	.51	.48
B ₂	.91	.34	.24	.19	—	—
C	1.29	.45	.40	.48	.63	.77

* Berkshire soils only.

As a rule, the greatest amount of oxalate-soluble manganese was found in the surface horizons, A₀ or A. Generally, the amount of this component in the extracts obtained from the C horizons was equal to or greater than that in the extracts obtained from the corresponding B horizons. The

mean, minimum and maximum values for extractable manganese, expressed as percentage of Mn_3O_4 removed from the soil, are tabulated below.

	A_0	A_2	B or B_1	B_2	C
Mean	.550	.009	.017	.024	.027
Minimum	.002	.000	.001	.011	.010
Maximum	.150	.037	.039	.039	.052

Since the quantities of oxalate-soluble iron, aluminium, titanium and phosphorus showed similar profile distributions they will be considered simultaneously. Of these four elements iron was considered to show the most characteristic distribution in the profiles of the soils examined. That is, the data for extractable iron accorded best with the generally-accepted picture of distribution under podzolization. Nevertheless, the quantities of all four of these elements extracted from the different horizons of the podzol profiles followed the same pattern. Thus, all were present in but small amounts in the A_2 , in considerably greater amounts in the B_1 , and in decreasing amounts in the B_2 . The pattern in the podzolic profiles was similar although the increase of soluble iron and aluminium in the B horizons was less marked. The ill-drained podzols, however, exhibited quite a different picture in this respect, as may be seen by reference to Table 5. In this table the mean values for the amounts of the four elements under consideration which were found in the extracts are given.

TABLE 5.—MEAN VALUES FOR OXALATE-SOLUBLE IRON, ALUMINIUM, PHOSPHORUS AND TITANIUM EXPRESSED AS PERCENTAGE OF DRY SOIL

Component	Horizon	Podzols	Brown podzolic	Ill-drained podzols
Fe_2O_3	A_0	.64	.77	.86
	A_2	.16	.26*	.36
	B_1	3.02	1.13	.20
	B_2	.75	.84	—
	C	.27	.31	.16
Al_2O_3	A_0	.29	.46	1.56
	A_2	.07	.47*	.27
	B_1	1.58	1.11	.13
	B_2	1.43	.70	—
	C	.38	.25	.08
P_2O_5	A_0	.086	.118	.206
	A_2	.017	.039*	.053
	B_1	.081	.083	.041
	B_2	.068	.073	—
	C	.038	.047	.050
TiO_2	A_0	.080	.124	.148
	A_2	.020	.071*	.052
	B_1	.147	.149	.033
	B_2	.082	.130	—
	C	.050	.035	.012

* Berkshire soils only.

The results for phosphorus suggested that the Tamm reagent was a comparatively good solvent for the compounds of this element present in these acid soils. The percentage of the total phosphorus extracted from the various horizons of two of the profiles under study is shown in Table 6

along with the percentage of phosphorus in organic combination as determined by Cann (1). Comparison of the values indicates that the Tamm reagent extracts both inorganic and organic compounds of phosphorus. This is evident when it is noted that 58.7% of the total phosphorus of the Magog A₀ horizon is oxalate-soluble whereas only 20% is inorganic, and that 28.2% is extracted from the Magog B horizon which contains only 3% of organic phosphorus.

TABLE 6.—PERCENTAGE OF TOTAL PHOSPHORUS, A, EXTRACTED BY THE TAMM REAGENT, B, PRESENT IN ORGANIC COMBINATION

Soil type	Horizon	A	B
Ascot sandy loam (Podzol)	A ₀	33.9	58
	A ₂	10.0	49
	B ₁	39.4	42
	B ₂	37.7	19
	C	27.7	4
Magog stony loam (ill-drained podzol)	A ₀	58.7	80
	A ₂	18.5	12
	B	28.2	3
	C	29.3	5

None of the components of the Tamm extract proved to be a suitable criterion for the differentiation of the soil types examined. The variability within a given soil type was too great. This point is illustrated in Table 7, which gives the extractable iron contents of the individual profiles examined.

TABLE 7.—OXALATE-SOLUBLE IRON EXPRESSED AS PERCENTAGE OF Fe₂O₃, REMOVED FROM THE SOIL

Soil	A ₂	B ₁	B ₂	C
Ascot sandy loam	.40	2.30	.65	.25
	.03	4.64	.64	.20
Greensboro loam	.13	2.28	.62	.36
	.10	1.18	1.35	.33
Greensboro loam, rolling phase	.05	3.93	.89	.12
	.23	3.69	.36	.33
Berkshire loam	.28	1.43	.87	.50
	.24	1.20	.90	.35
Woodbridge loam	—	.80	.68	.23
	—	1.09	.90	.16
Magog stony loam	.18	.11	—	.27
	.24	.33	—	.08
Brompton stony loam	.91	.28	—	.16
	.32	.18	—	.22
	.14	.07	—	.09

Examination of this table shows, for example, that on the basis of the oxalate-soluble iron in the B horizons Ascot soils might be confused with Greensboro soils, Greensboro with Berkshire, and Magog with Brompton.

The data for the other components of the extracts were equally inefficient in providing a basis for differentiation at the soil type level. The magnitude of the variability among replicate profiles which is illustrated in Table 7 indicates that it is not practicable to obtain such differentiation by studying larger numbers of profiles of these soil types.

SUMMARY

An attempt has been made to apply the acid ammonium oxalate extraction method of Tamm to the differentiation of soil types. Duplicate, in one instance triplicate, profiles of 7 soil types of podzolic origin were examined. The amounts of silicon, manganese, iron, aluminium, phosphorus and titanium extracted were determined.

The results obtained indicated that the Tamm method is incapable of providing criteria for the differentiation of podzol or podzolic soils at the soil type level.

The Tamm reagent proved to be a comparatively good solvent for the phosphorus compounds in these podzolized soils. It is capable of extracting both organic and inorganic compounds of phosphorus.

REFERENCES

1. CANN, D. B. Acid solubility of inorganic phosphates in Quebec soils. M.Sc. Thesis, McGill University, 1940.
2. CANN, D. B. and P. LAJOIE. Soil survey of Stanstead, Richmond, Sherbrooke and Compton counties. Dom. Dept. of Agr. Tech. Bul. 45. 1942.
3. DYER, W. J. and W. D. MCFARLANE. A study of the iron in a podzol soil by means of an improved dipyriddy method. Can. J. Res. B, 16 : 91. 1938.
4. DYER, W. J. and C. L. WRENSHALL. An improved method for the determination of phosphate by photoelectric colorimetry. Can. J. Res. B, 16 : 97. 1938.
5. HILLEBRAND, W. F. and G. E. F. LUNDELL. Applied Inorganic Analysis. J. Wiley and Sons, New York. 1929.
6. HOON, R. C. The distribution of sesquioxides, silica and organic matter in forest soil profiles of the Kulu Hill area. Indian Forest Records, n.s., Silvicultural Series, 1 : 347. 1936.
7. LUNDBLAD, K. Studies on podzols and brown forest soils. I. Soil Science, 34 : 137. 1934.
8. RICHARDS, B. Colorimetric determination of manganese in biological material. Analyst 55 : 554. 1930.
9. TAMM, O. Eine Methode zur Bestimmung der Anorganischen Komponenten des Gelkomplexes in Boden. Meddel. Stat. Skogsforsöksanst. (Sweden), 19 : 385. 1922. Cited by Lundblad (7).

A STUDY OF THE VARIABILITY OF CERTAIN CHEMICAL PROPERTIES IN SOILS¹

A. J. MACLEAN² AND R. SUMMERBY³

Macdonald College, Quebec

Soil heterogeneity as reflected in yields of experimentally grown crops has been noted by agronomists for many years. Harris and Scofield (7), Garber and Hoover (6) have shown the permanence of differences in experimental plots over a period of years. This would seem to indicate that in many cases at least, heterogeneity in crop yields is not due to transient effects of previous crops, but to real differences in the soil itself. While soil chemists too have been aware of soil variability, and have considered it in relation to soil sampling, in the main it has not been given the same attention accorded it by agronomists.

The Macdonald College Soil Fertility Committee has carried on during the past few years, soil fertility studies on farms in the region of Sawyerville, Compton County, Quebec. In 1937 and 1938 when new areas were selected for this work, it was deemed advisable to obtain some information on the uniformity of these areas in respect to chemical properties. Such information should be suggestive of how intensive a sampling procedure should be, to represent adequately the soils of this region. It should also throw some light on how suitable such areas as those selected are for experimental purposes, and should provide some guidance in the selection of plots from experimental areas for chemical studies. While the results to be presented cannot be applied in full to other areas, they do indicate the degree, and to some extent the pattern, of soil variability that may be encountered.

REVIEW OF LITERATURE

It is to be expected in cases where row applications of fertilizers have been made in large amounts, that the soil will have been made variable. This is shown in the studies of Horton and Stinson (8) where it was found that the residual effects of fertilizer application to tobacco soils presented a sampling problem. Again, a constituent such as nitrate would be expected to be variable. This has been shown to be true in investigation by Waynick (17), Prince (11), Karraker (9), and Blaney and Smith (2).

It is of interest to note the variation in chemical properties which has been found to exist in what were considered to be uniform fields. Robinson and Lloyd (12) were among the first to make a study of the magnitude of field sampling errors due to the variability in the soil from point to point, where samples are taken. Phosphoric acid and organic matter estimates on 15 borings from a field of uniform appearance, indicated the field errors of a boring to be of greater magnitude than the laboratory errors.

¹ Contribution from the Faculty of Agriculture, McGill University, Macdonald College, Que., Canada. Macdonald College Journal Series No. 194 representing a part of a M.Sc. thesis presented at McGill University by A. J. MacLean. Presented before a meeting of the Soils Group of the Canadian Society of Technical Agriculturists at Toronto, June 27-29, 1944.

² Formerly Graduate Assistant in Soil Fertility, Macdonald College, now employed with Canadian Defence Industries Ltd., Nitro, Que.

³ Professor and Chairman of Department of Agronomy.

Bear and McClure (1) determined the total nitrogen content of 45 borings taken to depth of $6\frac{3}{4}$ inches in case of surface samples, and from $6\frac{3}{4}$ to $13\frac{1}{4}$ inches in case of subsurface samples, from a 1/20-acre plot chosen for its uniformity. The nitrogen content varied from 0.118 to 0.243% in subsurface soil.

Waynick and Sharp (18) determined total nitrogen and carbon of 100 borings taken to a depth of 1 foot from each of two areas about 1.1 acres in size, selected for their uniformity. The field sampling errors exceeded the laboratory errors. In the case of one of the areas, the coefficient of variability for nitrogen, as well as for carbon, was found to be 9.00%. In the other area the coefficients of variability were 21.87 and 25.11% for nitrogen and carbon, respectively.

Frear and Erb (5) employed three methods in sampling two one-eighth-acre plots. Loss on ignition, nitrogen, potassium and phosphoric acid were determined. They report that despite unusual care, the sampling error remains greater than laboratory error.

Prince (11) determined in duplicate the total nitrogen content of each of 25 samples distributed over each of three plots which had received different treatments for a period of years prior to sampling. The coefficient of variability of the field samples was higher than that estimated from laboratory duplicates, in the case of each plot. However, the plots were found to be relatively uniform, the highest coefficient of variability being 5.57%.

Collins and Hodgen (3) studied variability of soils represented at five locations serving as sites for peanut production in North Carolina. A composite sample of 9 borings was taken from each 1/50-acre plot. On 144 plots at each location, tests for potassium, magnesium, calcium, phosphorus and pH were made by Hester's method, slightly modified. Considering that the fields were selected as uniform, the variations suggest necessity of careful sampling.

Youden and Mehlich (20) report a study of the variability of two soils not under cultivation, and representative of soils which might be studied in a soil survey in determining a soil type. Samples were taken at distances of 10 feet, 100 feet, 1000 feet and 1 to 3 miles, and pH determined. They conclude that intervals of 10 or 100 feet are too small for effective sampling.

MATERIALS AND METHODS

The studies to be reported are based on soils of experimental plots on each of four farms, in the Eastern Townships region of Quebec. These farms are designated as the B, McK, H and M farms, and they are located in the vicinity of Sawyerville, Quebec.

A description of the soils of this region may be obtained from the Soil Survey report of the area (13). All the experimental areas are located in the podzol zone on what has been mapped as a Greensboro loam. It is reported that the underlying formation is Ordovician black and grey slates and interbedded limestones, with some schistose material. The parent material is of glacial till, and contains impure limestone and slate. The drainage is reported to be good.

From observation the selected farms would appear to be typical of the region, and the usual rotation is a crop of oats, followed by hay crops, until yields become unduly low. The chief fertilizer application has been farmyard manure. All the experimental areas are located on a gentle slope. At time of selection each area was in sod, and all were ploughed and disced before sampling. From within duplicate blocks on each area, 7 plots were chosen at random from 21 plots comprising a block. Each selected plot was divided into halves, and these two half-plots constituted the units sampled for soil variability studies. On the B and McK farms the plots are 13 feet \times 16.75 feet, and are separated by 2 ft. alleys. On the H and M farms, the plots are 10 feet \times 20 feet, and are separated by 3 ft. alleys. Following plowing and disking of the soil, a composite sample was taken from each half-plot. On the B and McK areas sampled in October 1937, each composite consisted of 8 uniformly distributed spade slices of soil to plough depth. In the case of the H and M areas, sampled in October 1938, each composite consisted of 6 uniformly distributed borings to plough depth, taken with a soil sampling tube $1\frac{3}{4}$ " in diameter.

As a measure of soil variability, the following analyses were made: pH, total nitrogen, easily oxidizable carbon, exchangeable potash, and easily soluble inorganic phosphorus. Measurements of pH were made by means of a Hellige pH meter, provided with a glass electrode, on 1-1 suspension of soil according to *Methods of Analysis* (10). Total nitrogen was determined by the Gunning-Hubbard method as outlined in *Methods of Analysis* (10). Carbon was determined by the method of Thomas and Williams (14), excepting that weighed 5-gram samples were used. In the determination of exchangeable potash, extraction and preparation for the estimation were done according to the method of Volk and Truog (16). The determination was completed as directed by Wilcox (19), the volumetric procedure being used. Easily soluble phosphorous was determined by the method of Truog (15) the readings being made visually with a Kennicott-Campbell-Hurley calorimeter. In the determination of pH with the method employed, the greatest discrepancy in readings on the same sample has been 0.05 pH unit. Single determinations only of pH were made. All other analyses were performed in duplicate.

DISCUSSION OF RESULTS

General Variability

The variation resolves itself into the following categories: variation between farms, variation between blocks within farms, variation between plots within blocks, variation between the halves of each plot, and where duplicate laboratory determinations were made, the variation between these duplicates, designated as subsamples. It is believed that a comparison of the sources of variation will give a picture of the nature of variability present.

The detailed analytical results are given in Appendix Tables I and II. These data have been treated statistically by means of the analysis of variance of Fisher (4). In making comparisons, *F* values are used. In Table 1 the variances for the sources of variation are given for each constituent, comparisons being made between variances in brackets.

TABLE 1.—COMPARISON OF SOURCES OF VARIABILITY OF CONSTITUENTS STUDIED

Sources of variation	D.F.	pH variance	Total N. variance	Easily oxid. C variance	Exchange- able potash variance	Easily sol. inorg. phosphorus variance	F. value	
							P : .05	P : .01
Between Farms	3	1.5781	0.026548	2.253	25811.2	23696.3	†	16.69
Between Blocks within farms	4	0.0587	0.000723	0.1077	2280.5	74.0		
Between Plots within blocks	48	0.0891	0.002048	0.3265	1586.3	74.5	2.56	3.74
Between Half-plots within plots	56	0.0056	0.000549	0.0944	803.8	28.6	†	1.90
Between Subsamples within half-plots	112	—	0.000007	0.0046	19.5	4.3	†	1.73

* Significant difference.

† Highly significant difference.

From Table 1, the following observations may be noted:

(1) There is greater variation between experimental areas on the different farms than within these areas in respect to all constituents considered. Although seasonal effect is confounded with the differences between farms, it is not considered to alter the general conclusion since it was found that farms sampled in the same year showed appreciable differences. Constituents such as total nitrogen and easily oxidizable carbon would not be expected to show measurable differences within the period in question.

(2) With the arrangement of blocks and plots employed, the variation between blocks was not shown to be different from the variation between plots within the blocks. An examination of the data of the individual farms involved in Table 1, however, showed that this did not hold true for the B farm in respect to phosphorus and potash, nor for the McK farm in respect to phosphorus in which cases the block variances exceeded the plot variances, using the .05 point. With reservation because of the exceptions noted, it may be stated that with the block and plot arrangement used, no appreciable gradient in respect to the content of the various constituents was found within the experimental area of each farm studied, as measured by the plot variances.

(3) There is greater variation between plots than between the halves of these plots in respect to all constituents studied. Considering the farms individually this did not apply in the case of the B farm in respect to nitrogen and carbon, nor in the case of the H, McK and M farms in respect to potash, although the latter two farms showed a trend in support of the general conclusion. It would seem in general that the soil variability studied here follows a random pattern, giving rise to appreciable differences between plots within the same block as measured by the half-plot variances. From the smaller half-plot variances it would appear that within limited areas such as those of the plots employed, less soil variability occurs.

(4) The invariably high half-plot variances as compared to subsample variances suggest soil variability as an important source of error in soil investigations.

TABLE 2.—STANDARD ERRORS OF A SINGLE PLOT WITHIN A BLOCK AND MEANS FOR VARIOUS CONSTITUENTS

Farms	D.F.	P.H.		Total nitrogen		Easily oxid. carbon		Exchangeable K ₂ O per acre		Easily soluble inorg. P ₂ O ₅ per acre	
		S.E.	Means	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean
				%	%	%	%	lb.	lb.	lb.	lb.
B	12	0.16	4.98	0.033	0.263	0.45	3.62	40.9	133.0	5.0	32.0
McK	12	0.17	5.05	0.033	0.303	0.55	3.68	58.8	96.0	5.8	34.0
H	12	0.21	4.87	0.031	0.309	0.29	3.27	30.2	95.0	6.5	37.0
M	12	0.51	5.42	0.071	0.306	0.85	3.34	17.2	85.0	53.6	75.0
All farms	48	0.30	5.08	0.045	0.295	0.57	3.48	39.8	102.0	27.3	45.0

Variation between Plots within a Block

In field experimentation, the precision is determined by the error to be associated with an individual plot. This error may be calculated from the plot variances of each farm, for each constituent considered. In Table 2 the standard errors to be associated with single plots within a block for each farm, and for the farms considered together, along with appropriate plot means are given for each constituent studied. These errors are made up of the error between plots within a block, the errors of soil sampling, and the laboratory errors. However, as the sampling for each plot consisted of 8 spade slices in the case of the B and McK farms, and 6 borings in the case of the H and M farms, from each half of the plot, it may be stated that the sampling has been fairly intensive. The laboratory errors are seen to be small, as revealed by the small subsample variances in Table 1.

It will be noted from Table 2 that the plots are subject to appreciable errors. The magnitude of these errors may be appreciated by referring them to the means of the different constituents, which are estimates of the amount of any constituent which a single plot may be expected to contain. The high variability of the area on the M farm in respect to all constituents except exchangeable potash suggests that this area is too variable for the purposes of experimentation. The relatively low plot error for the M farm and the high plot errors for the B and McK farms in respect to exchangeable potash, would seem to indicate that in this region exchangeable potash cannot be used as a criterion of general variability of the soil.

Following different treatments it is often desirable to measure and to compare the relative levels of a chemical constituent in the soil. From the Standard Errors in Table 2, the differences required for significance between means of any number of plots may be computed for each constituent. In Table 3, the differences required for significance between means of 2, 4, 6 and 8 replicate plots are given for each farm, and on the

TABLE 3.—DIFFERENCES REQUIRED FOR SIGNIFICANCE BETWEEN MEANS OF 2, 4, 6 OR 8 REPLICATE PLOTS FOR VARIOUS CONSTITUENTS WHEN $P = .05$

Farm	Number of plots in mean	pH	Total nitrogen	Easily oxid. carbon	Exchangeable K_2O per acre	Easily soluble inorg. P_2O_5 per acre
			%	%	lb.	lb.
B	2	0.31	0.066	0.90	81.8	10.0
	4	0.22	0.048	0.64	57.8	7.0
	6	0.18	0.040	0.50	47.2	5.6
	8	0.16	0.034	0.45	41.0	5.1
McK	2	0.34	0.066	1.10	117.6	11.6
	4	0.22	0.048	0.78	83.2	8.2
	6	0.20	0.040	0.62	68.0	6.8
	8	0.17	0.034	0.54	58.8	5.9
H	2	0.42	0.062	0.58	60.4	13.0
	4	0.32	0.046	0.42	42.8	9.2
	6	0.24	0.036	0.34	34.8	7.6
	8	0.21	0.031	0.28	30.2	6.5
M	2	1.02	0.142	1.70	34.4	107.2
	4	0.70	0.102	1.20	24.4	75.8
	6	0.60	0.082	1.00	19.8	62.0
	8	0.51	0.070	0.85	17.2	53.7
All farms	2	0.60	0.090	1.14	61.6	54.6
	4	0.42	0.064	0.82	43.6	38.6
	6	0.34	0.050	0.64	35.6	31.4
	8	0.31	0.045	0.56	30.8	27.4

basis of all farms for each constituent considered. On the basis of the areas studied and with the method of sampling employed, small differences following treatments could not be assumed to be real. But it may be assumed that only 5 out of 100 times would differences exceeding those given in Table 3 occur by chance. The effectiveness of replication in increasing the accuracy of experiment, so that smaller differences due to treatment may be measured, is illustrated.

In the designing of an experiment to measure the effects of different treatments, the question arises as to how many replicate plots are required. The number will depend on the variability of the soil, the size of the differences it is desired to measure, and the probability we are willing to accept that our differences are real and not due to chance. For the area studied the number of replicate plots required to measure any desired difference may be calculated from the errors in Table 2, for any of the constituents considered. For example, if following treatments it is desired to make comparisons of the nitrogen content of plots and to detect differences as small as .030%, the number of plots required on the basis of the plot error for all farms ($\pm .045\%$) is found to be 18. Only 5 out of 100 times would a difference between means of 18 replicate plots, exceeding .030%, occur by chance.

It is believed that the observations made are at least suggestive of the importance of certain factors relative to field technique in chemical studies of soils.

SUMMARY AND CONCLUSIONS

The variability of pH, total nitrogen, easily oxidizable carbon, exchangeable potash and easily soluble inorganic phosphorus was investigated on experimental areas on each of four farms in the Eastern Townships of Quebec. Analyses for the above constituents were made on composite samples from each half of 7 random plots, from each of two blocks on each farm.

With the arrangement of blocks and plots employed, the variation between blocks was not shown to be different from the variation between plots within the blocks. It would appear that no definite gradient exists across these experimental areas.

On the basis of all farms, the standard errors of single plots for pH, percentage total nitrogen, percentage easily oxidizable carbon, exchangeable potash (lb. K_2O per acre) and easily soluble inorganic phosphorus (lb. P_2O_5 acre), were found to be 0.30, 0.045, 0.57, 39.8 and 27.3, respectively. The differences required for significance between means of 2, 4, 6 or 8 replicate plots were calculated for each constituent. It was shown that following treatment small differences could not be assumed to be real. The effectiveness of replication in increasing the accuracy of an experiment so that smaller differences could be measured was illustrated.

The significantly higher half-plot variances as compared to those computed from duplicate laboratory determinations, indicates that attention should be given to sampling of soils for chemical studies.

Realizing the complexity of soil variability and that only the ploughed layer has been studied, as well as the fact that a number of factors give rise to variable stands on plots treated alike, it is not supposed that results from chemical studies will parallel those of uniformity trials. However, some correlation is expected. The studies reported have indicated the M farm to be especially variable. This was borne out in marked irregularities which occurred in stands of clover on this experimental area. It would appear that studies of the sort reported afford a means of eliminating areas unsuitable for soil fertility studies.

ACKNOWLEDGMENTS

Appreciation is expressed to Dr. W. A. DeLong for guidance in connection with the chemical aspects of this problem, and to H. F. Salisbury who performed a number of the analyses for nitrogen.

REFERENCES

1. BEAR, F. B. and G. M. MCCLURE. Sampling soil plots. *Soil Sci.* 9 : 65. 1920.
2. BLANEY, J. E. and J. B. SMITH. Sampling market-garden soils for nitrates. *Soil Sci.* 31 : 281. 1931.
3. COLLINS, E. R. and W. R. HODGEN. Field variation as a factor in sampling for rapid soil analyses. *Assoc. Southern Agr. Workers. Proc. Ann. Meeting* 41 : 77. 1940.
4. FISHER, R. A. *Statistical Methods for Research Workers.* Oliver and Boyd, Edinburgh. 1936.
5. FREAR, W. and E. S. ERB. A study in soil sampling. *Journ. A.O.A.C.* 4 : 98. 1920.
6. GARBER, R. J. and M. M. HOOVER. Persistence of soil differences with respect to productivity. *Jour. Amer. Soc. Agron.* 22 : 883. 1930.

REFERENCES—*Concluded*

7. HARRIS, J. A. and C. S. SCOFIELD. Permanence of differences in the plots of an experimental field. *Jour. Agr. Research* 20 : 335. 1920.
8. HORTON, H. A. and F. A. STINSON. Investigations in sampling soils previously fertilized for flue-cured tobacco. *Sci. Agric.* 19 : 616. 1939.
9. KARRAKER, P. E. The variable occurrence of nitrates in soils. *Soil Sci.* 24 : 259. 1927.
10. METHODS OF ANALYSIS OF THE ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS. (5th ed.). 1940.
11. PRINCE, A. L. Variability of nitrates and total nitrogen in soils. *Soil Sci.* 15 : 395. 1923.
12. ROBINSON, G. W. and W. E. LLOYD. On the probable error of sampling in soil surveys. *J. Agr. Sci.* 7 : 144. 1915.
13. CANN, D. B. and P. LAJOIE. Soil Survey of Stanstead, Richmond, Sherbrooke and Compton Cos., Que. *Dom. of Can. Tech. Bul.* 45. 1942.
14. THOMAS, R. P. and R. C. WILLIAMS. A comparison of the results of rapid tests with the amounts of available nutrients obtained by quantitative methods on Maryland soils. *Soil Sci. Soc. of Amer., Proc.* 1 : 243. 1936.
15. TRUOG, E. The determination of the readily available phosphorus of soils. *Jour. Amer. Soc. Agron.* 22 : 874. 1930.
16. VOLK, N. J. and E. TRUOG. A rapid chemical method for determining the readily available potash of soils. *Jour. Amer. Soc. Agron.* 26 : 537. 1934.
17. WAYNICK, D. D. Variability in soils, and its significance to past and future soil investigations. 1. A statistical study of nitrification in soil. *Univ. Calif. Pub. Agric. Sci.* 3 : 243. 1918.
18. WAYNICK, D. D. and L. T. SHARP. Variability in soils and its significance to past and future soil investigations. II. Variations in nitrogen and carbon in field soils and their relation to the accuracy of field trials. *Univ. Calif. Publ. Agric. Sci.* 4 : 121. 1919.
19. WILCOX, L. V. Determination of potassium. *Ind. and Eng. Chem., Anal. Ed.* 9 : 136. 1937.
20. YODEN, W. J. and A. MEHLICH. Selection of efficient methods for soil sampling. *Contrib. Boyce Thompson Inst.* 9 : 59. 1937.

TABLE I.—ANALYSES OF SAMPLES FROM B AND MCK FARMS FOR pH , TOTAL NITROGEN, EASILY OXIDIZABLE CARBON, EXCHANGEABLE POTASH AND EASILY SOLUBLE INORGANIC PHOSPHORUS

Plot	pH	Total N (%)				Easily oxid. C (%)				Exchangeable potash (lb. K ₂ O per acre)				Easily sol. inorg. phosphorus (lb. P ₂ O ₅ per acre)				
		Half-plot A		Half-plot B		Half-plot A		Half-plot B		Half-plot A		Half-plot B		Half-plot A		Half-plot B		
		Orig.	Dup.	Orig.	Dup.	Orig.	Dup.	Orig.	Dup.	Orig.	Dup.	Orig.	Dup.	Orig.	Dup.	Orig.	Dup.	
B FARM: Block 1	2	5.00	.221	.221	.260	.265	3.12	3.18	3.79	3.73	161	155	143	148	34	33	32	33
	4	5.10	.227	.228	.270	.270	3.34	3.34	3.92	4.04	180	187	173	160	28	28	27	27
	8	4.90	.258	.260	.290	.287	3.73	3.40	3.73	3.83	147	148	144	142	34	36	38	39
	9	4.85	.266	.262	.245	.248	3.86	3.76	3.52	3.46	144	136	132	139	30	31	26	29
	13	4.95	.289	.291	.251	.249	3.67	3.73	3.09	3.27	139	132	108	114	31	30	30	32
	17	5.05	.276	.280	.290	.293	4.04	3.98	4.59	4.31	167	170	137	145	27	25	31	29
	21	5.00	.219	.218	.277	.280	3.12	3.12	3.89	3.86	142	139	123	120	28	30	32	34
Block 2	4	5.25	.224	.227	.274	.277	3.24	3.37	3.95	3.89	87	95	105	97	34	36	36	34
	5	4.95	.249	.250	.238	.238	3.61	3.49	3.61	3.70	156	138	146	138	28	30	33	36
	7	5.00	.291	.291	.273	.274	3.76	3.73	3.73	3.73	167	167	145	166	31	32	31	34
	9	4.90	.287	.291	.270	.269	3.76	3.83	3.70	3.76	116	113	139	131	32	32	36	33
	13	4.80	.231	.237	.293	.296	3.18	3.09	3.83	3.89	88	93	129	138	36	33	37	36
	16	4.85	.280	.276	.290	.291	3.61	3.64	3.58	3.52	100	98	108	119	37	34	34	34
	19	5.15	.260	.262	.241	.241	3.24	3.40	3.21	3.34	113	100	105	109	36	40	32	31
McK FARM: Block 1	1	4.85	.314	.317	.329	.328	3.70	3.83	3.92	3.83	129	131	110	116	38	38	41	38
	2	5.05	.300	.295	.318	.318	3.89	3.79	3.89	4.01	105	117	63	71	32	34	34	38
	4	5.10	.298	.299	.311	.311	3.86	3.89	3.76	3.86	93	87	113	113	28	30	31	31
	11	4.90	.309	.307	.344	.343	3.86	3.89	4.31	4.22	116	110	91	79	41	37	38	34
	17	4.85	.314	.314	.284	.288	3.73	3.83	3.18	3.18	116	103	88	93	40	43	38	40
	18	4.80	.314	.291	.308	.290	3.86	3.79	3.30	3.21	105	101	98	96	40	38	31	34
	21	5.20	.304	.302	.300	.300	3.61	3.70	3.61	3.64	74	68	105	102	33	34	28	31
Block 2	1	4.90	.284	.286	.279	.277	3.16	3.34	3.24	3.34	94	90	91	84	36	34	36	32
	6	5.10	.286	.287	.283	.283	3.55	3.61	3.18	3.30	112	111	255	243	31	29	32	30
	7	5.25	.301	.307	.269	.270	3.09	3.12	3.83	3.83	70	67	71	70	32	31	33	34
	18	5.05	.301	.304	.302	.304	3.70	3.64	3.70	3.67	71	72	70	72	30	30	31	30
	19	4.95	.297	.294	.304	.300	3.43	3.40	3.49	3.55	98	106	79	76	38	34	33	31
	20	5.15	.273	.288	.293	.288	3.37	3.40	3.37	3.46	73	71	56	63	31	31	30	31
	21	5.75	.344	.344	.339	.336	4.35	4.31	4.25	4.35	81	73	75	78	33	34	31	30

APPENDIX—Concluded

TABLE II.—ANALYSES OF SAMPLES FROM H AND M FARMS FOR PH, TOTAL NITROGEN, EASILY OXIDIZABLE CARBON, EXCHANGEABLE POTASH AND EASILY SOLUBLE INORGANIC PHOSPHORUS

	Plot	pH		Total N (%)				Easily oxid. C (%)				Exchangeable potash (lb. K ₂ O per acre)				Easily sol. inorg. phosphorus (lb. P ₂ O ₅ per acre)			
		Half-plot A	Half-plot B	Half-plot A		Half-plot B		Half-plot A		Half-plot B		Half-plot A		Half-plot B		Half-plot A		Half-plot B	
				Orig.	Dup.	Orig.	Dup.	Orig.	Dup.	Orig.	Dup.	Orig.	Dup.	Orig.	Dup.	Orig.	Dup.		
H Farm: Block 1	4	4.85	4.90	.323	.324	.324	.324	3.34	3.24	3.49	3.70	81	86	94	105	34	36	31	36
	6	4.90	4.85	.323	.319	.318	.323	3.55	3.64	3.27	3.37	100	100	90	91	34	38	36	38
	7	4.80	4.85	.308	.309	.306	.305	3.21	3.12	3.30	3.21	84	77	84	84	38	34	32	33
	8	4.95	4.95	.288	.287	.306	.312	3.00	2.94	3.27	3.15	87	94	97	103	34	36	36	38
	10	5.20	5.25	.291	.290	.314	.309	3.12	3.00	3.15	3.12	86	87	161	162	38	41	40	41
	14	5.00	4.80	.265	.268	.287	.280	3.12	3.03	3.27	3.37	77	77	96	103	41	39	35	38
	20	4.80	5.00	.308	.306	.336	.337	3.34	3.34	3.52	3.55	87	89	110	113	36	38	40	41
Block 2	1	5.15	5.15	.296	.296	.291	.291	3.21	3.06	2.94	2.85	76	70	77	79	34	38	34	35
	4	4.90	4.80	.309	.306	.298	.293	3.30	3.40	3.27	3.15	99	98	84	77	32	33	31	32
	7	4.70	4.70	.301	.297	.304	.306	3.43	3.40	3.21	3.24	78	78	84	80	34	38	34	37
	15	4.80	4.70	.307	.306	.324	.319	3.52	3.43	3.30	3.45	105	98	94	86	33	34	34	36
	16	4.75	4.75	.339	.321	.302	.298	3.27	3.34	3.30	3.34	89	90	89	97	38	39	44	42
	18	4.75	4.70	.323	.327	.350	.334	3.30	3.27	3.27	3.37	93	92	162	163	40	41	45	45
	20	4.75	4.60	.327	.322	.308	.308	3.27	3.27	3.30	3.21	100	95	79	84	40	41	36	38
M Farm: Block 1	1	5.80	5.90	.342	.344	.334	.337	3.89	3.79	3.79	3.76	88	84	80	84	102	107	115	117
	5	5.35	5.35	.244	.247	.288	.282	2.69	2.75	2.97	2.94	78	77	75	77	48	53	49	53
	11	5.30	5.40	.318	.317	.322	.327	3.27	3.40	3.46	3.46	89	95	100	99	76	77	60	62
	13	5.05	5.05	.310	.292	.292	.290	3.00	2.88	3.18	3.18	82	82	74	69	59	56	52	50
	15	6.30	6.35	.344	.348	.386	.380	3.89	3.73	4.10	4.01	78	84	98	96	143	130	137	146
	19	5.20	5.35	.278	.279	.282	.285	3.18	3.18	2.97	2.94	72	72	89	84	51	55	60	62
	21	5.00	5.10	.293	.294	.283	.282	3.09	3.12	3.18	3.21	79	80	83	88	45	44	45	43
Block 2	4	5.25	5.25	.302	.303	.290	.289	3.27	3.27	3.06	3.18	92	90	72	74	71	71	76	71
	5	5.30	5.20	.272	.269	.274	.267	2.97	3.00	2.88	2.75	77	82	86	80	88	89	76	69
	16	5.75	5.80	.356	.355	.357	.357	3.98	3.95	4.01	4.01	103	100	79	75	96	103	96	102
	17	5.35	5.50	.343	.346	.352	.354	4.01	3.92	3.98	3.98	115	121	100	92	66	64	73	73
	18	5.50	5.45	.300	.294	.316	.313	3.18	3.37	3.34	3.46	82	89	71	77	61	64	64	66
	20	5.25	5.25	.263	.277	.294	.273	2.94	3.00	3.12	3.06	85	88	89	79	60	59	68	66
	21	5.15	5.20	.288	.288	.274	.271	3.21	3.24	3.15	3.15	79	81	77	74	71	75	90	92

RAPID SOIL TESTS ON SOME CARLETON COUNTY SOIL¹

H. J. ATKINSON², P. O. RIPLEY,³ AND L. M. PATRY⁴

The county of Carleton in the Province of Ontario has an estimated land area of 585,600 acres. The soil survey mapped 25 different soil groups, comprising 37 soil types. The eleven largest groups being farmed together make up nearly 75% of the total land area (Table 1). Muck and peat soils cover an area of 60,480 acres. Granby sand and sandy loam occupy 13,760 acres, but little of this is farmed.

Since the soil survey was made in 1941, certain lines of investigation have been carried out in connection with some of the major soil types with a view to learning something about their relative present and potential fertility levels as well as the adaptation of different field crops for growth on these soils. This work has been conducted by the Division of Field Husbandry, Experimental Farms Service, with collaboration by the Division of Chemistry, Science Service, wherever chemical studies were required.

Soil samples from the eleven types listed in Table 1 were brought into the greenhouse, placed in glazed pots of 1 gallon capacity and treated with commercial fertilizer of different formulae and at various rates. Samples were obtained from two farms on each soil type in 1941 (only one farm on the Uplands, Grenville and Carp types) and fresh samples were taken in 1942, in most cases from the same farms. An attempt was made to select one farm on each type where the number of head of livestock kept had been relatively high and where fairly large amounts of manure had been returned to the soil, thus presumably raising the fertility level somewhat above the average. The other farm on each soil type was selected where the system of farming did not provide for the keeping of so much livestock and where probably the fertility level was normal or somewhat below normal. The purpose of this selection was to study the effect of two different systems of farm management on the productivity of the various soil types.

The crops grown in the greenhouse were barley followed by red clover in 1941-42, and oats followed by alfalfa in 1942-43. Fertilizer treatments included the following:

1. Check—no treatment.
2. Nitrogen—40 lb. N per acre.
3. Phosphorus—80 lb. P_2O_5 per acre.
4. Potassium—60 lb. K_2O per acre.
5. Nitrogen and phosphorus.
6. Nitrogen and potassium.
7. Phosphorus and potassium.
8. Nitrogen, phosphorus and potassium.

The fertilizer was applied in the form of sulphate of ammonia, super-phosphate (20%) and muriate of potash, applied in a layer 1 inch below

¹ Paper presented before the Soils Group of the Canadian Society of Technical Agriculturists in Toronto June 28, 1944. Joint contribution from the Division of Chemistry, Science Service, and the Division of Field Husbandry, Experimental Farms Service. Scientific Contribution No. 116, Division of Chemistry, Science Service.

² Associate Chemist, Division of Chemistry.

³ Assistant, Division of Field Husbandry.

⁴ Junior Chemist, Division of Chemistry.

the grain which was seeded 1 inch deep. In 1941-42 one application was made for barley which was grown to maturity. After harvesting the barley, the surface soil was stirred and a second application was put on immediately previous to seeding red clover. The latter was sown $\frac{1}{2}$ inch deep. In 1942-43 only one application was made when seeding oats and alfalfa. The fertilizer was placed in a layer 2 inches from the surface, then 1 inch of soil was replaced and the oats seeded 1 inch deep, then $\frac{1}{2}$ inch of soil was replaced and the alfalfa was broadcast and covered with $\frac{1}{2}$ inch of soil. The oats and alfalfa grew in the same pot in a manner simulating field practice.

Soil samples for laboratory examination were taken from the soils used in the greenhouse work in 1941-42 and also in 1942-43. Thus, in most cases, there were four samples from each soil type. The following determinations were made on the air-dried samples: pH, moisture, loss on ignition, nitrogen, phosphorus, exchangeable lime, magnesia and potash, readily soluble phosphoric acid by the Ruhnke method, rapid tests for lime, magnesia, potash and phosphoric acid on all samples by the Spurway and the Morgan methods, rapid tests for potash and phosphoric acid by the Thornton method on the 1941 samples, and rapid tests for phosphoric acid by the Guelph modification of the Thornton method on the 1941 samples.

The purpose of this paper is to attempt to assess the value of the various rapid methods of soil testing when applied to a series of soil types, of varying texture, and on which several species of crops are grown. To do this, the results of the tests will be discussed in relation to the response to fertilizer applications as measured by the yields of the various crops grown under greenhouse conditions. The tests were applied, without modification, according to the directions given in the methods as published.

The response of the crop to each of the three main fertilizer elements N, P and K has been expressed as a percentage increase in yield due to that element when used alone and with each of the other elements. Thus, for nitrogen, the percentage increase of the N-treated pots over the check was determined, also that for NP over P, for NK over K, and for NPK over PK. The average of these has been taken as a measure of the response to N fertilization. Similar calculations were made for the elements P and K.

In order to give some idea as to the relative productivity of the different soil types, the actual yields in grams per pot obtained from the untreated soils are presented in Table 2.

RESULTS

Uplands Sand

The first soil type to be considered is the Uplands sand, where work was carried out on samples from the J. Stewart farm in both years and from the R. Lecuyer farm in 1942. The response (Table 3) of the cereals to nitrogen was very marked (+ 374% for barley and + 146% for oats on the Stewart soil, + 75% for oats on the Lecuyer soil). The growth of the legumes, however, was apparently depressed by N (− 9% for clover and − 45% for alfalfa on the Stewart soil, − 29% for alfalfa on the Lecuyer soil). The total soil nitrogen was very low (less than 0.1%) on these soils.

The response to phosphorus was much less marked. An increase of 28% on clover on the Stewart soil and 30% on oats on the Lecuyer soil was shown, but in all other cases, although there was an average increase, it was always less than 20% and the individual results showed a wide variation. The rapid soil tests for P showed considerable variation, L-VVL by Spurway's method, MH-L by Morgan's, VH by Thornton's and H by the Guelph modification. The readily soluble P_2O_5 by the Ruhnke method on the Stewart samples was 53 and 80 p.p.m., which was considered to be somewhat low, and, on the Lecuyer soil, 100 p.p.m. which was thought to be adequate.

The response to potassium was not great. Although an average increase of 34% was obtained on clover on the Stewart soil, and 32% on alfalfa on the Lecuyer sample, in all other cases the average increase was less than 12%. Since all rapid soil tests were either low or very low, and the exchangeable potash was very deficient (considerably less than 0.015%), a more general response to potash fertilizers might have been expected.

Rubicon Sand

Samples on this soil type were taken from the Saunders and Hawkins farms. The response (Table 4) of cereals to nitrogen was very good, though less than that obtained on Uplands sand. The average figures are +62% for barley and +25% for oats on the Saunders soil, +58% for barley and +48% for oats on the Hawkins soil. The growth of clover was scarcely affected (−5% in the one case, +3% in the other) though alfalfa gave increases of 26% and 22% on the two soils. The total soil nitrogen was on the low side (between 0.10% and 0.21% on four samples).

Cereals on the Saunders soil showed no definite response to phosphorus (+8% for barley, −2% for oats). On the Hawkins soil, phosphorus gave a 24% increase with barley but a 10% decrease with oats. The results on the legumes were erratic. On the Saunders soil, an 8% decrease with clover and a 24% increase with alfalfa were recorded, but on the Hawkins soil, the results were an 18% increase on clover and a 5% decrease on alfalfa. The rapid soil tests for P again showed a wide variation, L-VL by Spurway's method, M-MH by Morgan's, M-L by Thornton's and H by the Guelph modification. The readily soluble P_2O_5 was low (39-74 p.p.m.) on three soil samples, but quite adequate (123 p.p.m.) on the fourth, the 1942-43 sample from the Hawkins farm. It was difficult to see any relationship here between tests and response to fertilizers.

With one exception (barley on the Saunders soil), there appeared to be a response to potash fertilization on this soil type. The increase is greater on the Hawkins soil than on the Saunders soil and greater with legumes than with the preceding cereals. The most outstanding increases were found with alfalfa, 85% on the Saunders soil and 162% on the Hawkins soil. All rapid soil tests recorded low or very low results, and the amounts of exchangeable potassium indicated a deficiency, so that a response to potash fertilizers was to be expected. However, amounts of exchangeable potassium were lower on the Uplands sand and nothing like the same response was obtained there.

Kars Gravelly Loam

Samples of this soil type were collected from the Redmond farm in both years, from the McMenemy farm in 1941 and from the L. Lecuyer farm in 1942. The response (Table 5) of cereals to nitrogen was very good, the averages ranging from 80% to 171%. On the other hand, there was a consistent decrease in the yield of legumes where nitrogen was applied, particularly in the case of alfalfa on the Lecuyer sample. The total nitrogen of the soil samples was generally low.

The response to phosphorus was almost negligible for all crops, the average figures ranging from - 2% to + 11%. Spurway's test gave low results in all cases, Morgan's, M-MH, Thornton's, H-VH and Guelph, H. The McMenemy sample gave only 46 p.p.m. readily soluble P_2O_5 , the Lecuyer sample 283 p.p.m., but neither showed any response to applied phosphorus.

Potassium was considered deficient by all tests. Nevertheless, there was no response by the cereals (-1% to +4 %) to potash fertilization. Alfalfa on both soil samples and clover on the McMenemy sample showed some response (+26% to +44%). A general response was to be expected.

Manotick Sandy Loam

Samples of this soil type were taken from the Lyttle farm in both years, from the McClure farm in 1941 and from the Goodwin farm in 1942. Again, a good response (Table 6) to nitrogen was obtained with cereals, an average of 67% and 39% with barley, 44% and 69% with oats. The legumes, however, did not respond to this treatment, the average results varying from - 2% to + 8%. The total nitrogen of the soil samples was not very high (0.15%-0.19%).

The average increases from phosphorus applied to cereals was less than 20% except with oats on the Lyttle soil where an average increase of 32% was obtained. On the other hand, very good increases (41%-85%) were obtained with legumes as the result of applications of phosphorus except with alfalfa on the Goodwin soil where the average increase was only 4%. Spurway's test (on the 1942-43 samples only) showed low amounts of phosphorus present, none of the others showed any amount higher than medium. The readily soluble phosphorus by the Ruhnke method was less than 65 p.p.m. with the exception of the Lyttle 1942 sample where the result was 222 p.p.m.

With the exception of alfalfa on the Goodwin soil, where potassium gave an average increase of 87%, there was little if any response to applied potash on this soil type. Clover on the Lyttle soil showed an average increase of 18%, but all other increases were less than 10% and a few slight decreases were recorded. All rapid tests gave low or very low readings, and the amounts of exchangeable potassium were generally deficient. A more general response to potash fertilization might have been expected.

Castor Fine Sandy Loam

Soil samples were obtained from the Waddell and Quaille farms. As with the previous soil types, the response (Table 7) of the cereals to nitrogen was quite marked, the increase being 57% and 95% for barley, 11% and

47% for oats. There was no response of the legumes to nitrogen, the results varying from + 4% to - 13%. The total soil nitrogen was 0.20%-0.21% on the Waddell samples, 0.14%-0.18% on the Quaile samples.

The response to phosphorus was extremely good with all crops on the Waddell sample, but particularly so with the oats (+ 154%) and the alfalfa (+ 239%). The response on the Quaile samples was much less marked, being less than 20% except on the clover crop which showed a 49% increase. Soil tests were L-VVL by Spurway's method, L-H by Morgan's, M-H by Thornton's and M-VH by the Guelph procedure. The readily soluble P_2O_5 was very high, 213-345 p.p.m. on the four samples. In general, crop responses showed best agreement with the results by the Morgan method.

Potassium gave some increase on the legume crops, 33% and 42% on clover, 27% and 9% on alfalfa. There was no significant response to potash fertilizers on the cereal crops, results ranging from + 4% to - 5%. Soil tests indicated that there should have been a response to K fertilization, as all rapid tests were low to very low and exchangeable potassium indicated a definite deficiency (all results less than 0.010%).

Farmington Loam

Samples were collected from the Featherstone and Fraser farms. While some response (Table 8) of cereals to nitrogen fertilization was shown, it was not as great as with most of the other types. Barley on the Featherstone soil gave an average increase of 65%, but in the other three cases, the average varied between 12% and 19%. In all cases there was an average decrease of from 2% to 17% in alfalfa yield due to applied nitrogen. The total nitrogen present in this soil type appeared to be satisfactory and varied from 0.20% to 0.34% in four samples.

With the exception of the barley and clover grown on the Featherstone 1941-42 sample, the response of all crops to phosphorus was very good, showing increases of 43% to 140% on the cereals, and 36% to 314% on the legumes. Tests were all low by Spurway's method, L-MH by Morgan's, M-H by Thornton's, and H by the Guelph modification. The amounts of readily soluble P_2O_5 appeared to be very satisfactory, 215 p.p.m. and 268 p.p.m. on the 1941-42 samples, 156 p.p.m. and 140 p.p.m. on the 1942-43 samples. The soil tests on the Featherstone and Fraser 1941-42 samples were almost identical but the Fraser soil gave a good response (+ 77% on barley, + 36% on clover) whereas the Featherstone soil showed practically none (- 7% on barley, + 10% on clover).

Clover showed some response to potassium applications on both soils (40% and 57%) but responses with other crops were small (- 2% to + 15%). All soil tests, including the determinations of exchangeable K, were low and a good response might reasonably have been expected.

Grenville Loam

Samples were collected from the Dow farm in both years and from the D. M. Stewart farm in 1942. There was some response (Table 9) by cereals to nitrogen applications, the average increases ranging from 26% to 41%, but again the legumes did not respond, there being an average decrease of 17% with alfalfa on the Stewart sample. The total amount of nitrogen in these samples was reasonably good, 0.25% to 0.29%.

Response to phosphorus was good with all crops on the Dow samples, and with alfalfa but not with oats on the Stewart sample. Morgan's test on the three samples were LM, M and MH; the readily soluble P_2O_5 was in the same order, 77, 92 and 121 p.p.m., respectively; and the response to applied P was greatest where the test showed the lowest amount present, and least where the test showed the greatest amount.

Clover on the Dow sample was the only crop to show any response to potassium and the average increase was only 23%. Tests showed this sample to be deficient in potassium. In both 1942-43 samples, the rapid tests gave low (in one case, medium) results but the amounts of exchangeable potassium (0.026% and 0.030%) were considered satisfactory. On neither of these samples was there response to added potassium.

Osgoode Loam

Samples were collected from the Brown and Nixon farms. The cereals responded to applications of nitrogen, the average increases varying from 19% to 58%. No definite response (Table 10) to nitrogen was observed in the case of the legumes. The 1942 Nixon sample had a very good supply of total nitrogen (0.45%) but the others had considerably less (0.15%-0.21%).

Clover, oats and alfalfa on the Brown soil showed a good response (51% to 86%) to applied phosphorus, but in no other case did the average increase exceed 17%. By Ruhnke's extraction method, these samples seemed to be well supplied with readily soluble P_2O_5 , the results varying from 322 p.p.m. to 511 p.p.m. P_2O_5 . Spurway's method gave readings from L to M, and Morgan's from M to H. The greatest response to applied P was obtained on the soil which gave a low reading by Spurway's method.

Alfalfa on the Brown samples gave an average increase of 65% when potassium was applied. In the other cases, no average increase was greater than 12%. Rapid soil tests registered VL or L (M by Spurway's method on the Nixon 1942 sample) and determinations of the exchangeable potassium showed that the amounts present were very small (not over 0.005% K_2O). A more general response to potassium fertilization might have been expected.

Carp Clay Loam

Samples were taken from the Ellis & Shaw farm in both years, and from the Hudson farm in 1942. Cereals showed a fairly good response (Table 11) to nitrogen, the averages ranging from 32% to 63%. The response of the legumes to nitrogen varied from - 6% to + 12%. The total amount of nitrogen in the soil samples was reasonably good, from 0.26% to 0.45%.

The legumes on the Ellis & Shaw samples showed good response to phosphorus, particularly alfalfa (+ 90%), but cereals gave no response (- 1% to + 3%). On the Hudson sample, oats gave an increase of 51%, when phosphorus was applied and alfalfa an increase of 168%. Spurway's test was VVL on the Hudson sample and L on the other two. Morgan's test was LM on the Hudson sample, MH on the others. Thus the response to added P was more or less in agreement with these tests. On the other

hand, the amount of readily soluble phosphorus as measured by the Runke method was quite high (240 p.p.m.—286 p.p.m. P_2O_5).

There was no response to potassium on any sample with any crop. Rapid soil tests gave low readings (medium by Spurway's method on one Ellis & Shaw sample) and the exchangeable potash was low (0.009%) on the Hudson sample and not any too high on the Ellis and Shaw samples. Some response to added potash might have been expected but none was obtained.

North Gower Clay

Soil samples were taken from the Kenny and Argue farms. The response (Table 12) of the cereals to nitrogen was again very good, from +32% to +50%, but again there was no response with the legumes (−6% to +8%). The total nitrogen content of the Kenny soil is fairly good (0.21%–0.24%) and that of the Argue soil is still better (0.30%–0.32%).

A good response to phosphorus was obtained in all cases except with oats on the Kenny sample where the average was only +4%. The outstanding increase was 168% with alfalfa on the Argue soil. The Spurway method gave readings of L-VVL, the Morgan method all M, the Thornton gave M-H and the Guelph modification H-VH. The readily soluble P_2O_5 was very high, 245–409 p.p.m. Results by the Spurway method are the only ones that would indicate such a marked response to applied phosphorus.

No response to potassium can be claimed for this soil type. All averages were between the limits of −4% and +10%. All rapid soil tests registered low (except for one medium, on the Argue 1942–43 sample by the Spurway method) and the exchangeable potassium was also somewhat on the low side. A response to potassium was to be expected but was not obtained.

Rideau Clay

Soil samples were collected from the Rowe and Kennedy farms. The response (Table 13) of cereals to applications of nitrogen held true with this soil type also, the averages varying from +19% to +64%. The legumes reacted to nitrogenous fertilization in a manner similar to that on the other soil types. The average increase with clover on the Rowe soil was 18%, but in the other three cases, decreases of from 3% to 16% were registered. Total soil nitrogen was 0.20% and 0.23% on the Rowe samples, and 0.33% and 0.34% on the Kennedy samples.

The response of cereals to phosphorus was +15% or less in three cases, but was +31% with barley on the Kennedy soil. The response of legumes was good (over +30%) in three cases but only +9% with clover on the Kennedy soil. Rapid soil tests by the Spurway method were VVL (1942–43 samples only), L-MH by the Morgan method, H by the Thornton method and VH by the Guelph modification. The Runke method showed abundant amounts (323–388 p.p.m.) of readily soluble P_2O_5 . Results by the Morgan method showed the best agreement with crop response, particularly in the case of the legumes.

With potassium, all crops showed a negative response (0 to −18%) except clover on the Rowe soil which gave an average increase of 14%.

The Spurway test showed M-MH amounts present; the Morgan test indicated low K in the 1941-42 samples but very high amounts the next year; the Thornton test showed low amounts of potassium in the 1941-42 samples. Exchangeable potash was high in all cases. Except for the Morgan test the first year, the results showed satisfactory amounts of potassium present so that no response was to be expected.

DISCUSSION

In a broad survey of the foregoing results, probably the most outstanding fact is the difference shown by the cereals and the legumes in their response to the fertilizer nutrients. This is well shown by taking the average percentage increases in yield of cereals and in yield of legumes for each fertilizer element on each soil type and arranging them as in Table 14. The response of cereals to nitrogen has been general on all soil types studied, varying from an average increase of 28% on the Farmington loam to one of 198% on the Uplands sand. On the other hand, the lack of response of legumes to nitrogen has also been general. The greatest increase was only 12% on Rubicon sand, no other increase was above 4%, and a decrease was shown on the majority of the soil types, particularly on Kars gravelly loam (− 17%) and on Uplands sand (− 28%).

The response to applied phosphorus was quite good for both cereals and legumes. On only two soil types (Kars gravelly loam and Rubicon sand) was the increase on both crops less than 10%. In all other cases, an increase of more than 15% was obtained, the greatest being 63% with the cereals and 118% with the legumes on the Farmington loam. In general, the legumes showed a greater response to applied phosphorus than did the cereals.

The cereals showed little if any response to the application of potassium. An average increase of 19% was obtained on Rubicon sand but, except for Uplands sand (+ 9%) the averages on all other soils varied from + 5% to − 5%. The response of the legumes to potassium was noticeably better. On four types (Grenville loam, North Gower clay, Carp clay loam and Rideau clay), the average response was only 10% or less; on all others it was more than 20%. On the Rubicon sand, where the response of the cereals to potassium was greatest (19%), the response of the legumes to potassium was also greatest (78%).

In some cases, the results in Table 14 indicate quite clearly the treatments most required by a particular soil type. For example, on the Rubicon sand, the response to nitrogen and potassium was quite good, but practically no response was obtained when phosphorus was used. The Rideau clay gave no increased growth of crops due to potassium, but some with phosphorus on both kinds of crops, and with nitrogen on the cereals. Crops grown on the Farmington loam showed the greatest increase from phosphorus; legumes on this type gave the second greatest increase from potassium; cereals, on the other hand, gave the least response to nitrogen on this soil type.

Although no rapid soil test for nitrogen was made in this study, it is perhaps of some interest to observe the relationship between total soil nitrogen and the response obtained when nitrogen was applied to the soil. In two cases, the average percentage increase due to N was over 100%, and here the total soil nitrogen was not greater than 0.10%. The next

three soils, listed in decreasing order of their average response, had nitrogen contents varying from 0.15% to 0.18%. In the remaining soils, the amount of nitrogen present ranged between 0.25% and 0.36%; on these, the cereals gave the lowest, though still considerable, increases (28% to 45%).

Rapid soil tests for phosphorus were made by four methods (Spurway, Morgan, Thornton and Guelph) in one year and by two of these (Spurway and Morgan) in the second year. The individual results, together with the response of the crops of applications of P, are given in Table 15. One point that seems to be of importance is the tendency of these tests to give readings within certain ranges regardless of the soil type being tested, although the actual yields, as shown in Table 2, indicate a marked difference in fertility levels. Out of 35 individual samples examined by Spurway's method, 32 gave readings of L, VL or VVL. The other 3, on samples of Osgoode loam, were recorded as medium. There were no high readings. Forty-one samples were tested according to Morgan's method and, of these, 31 were recorded as M or MH. There were only two high readings. By Thornton's method, 16 out of 19 were M or H, 2 were VH and 1 L. When using the Guelph modification, 16 out of 19 were either H or VH, the other 3 being M and none was L. Thus there appeared to be a tendency for readings to be low by the Spurway method, medium to high by the Morgan and Thornton methods, and high to very high by the Guelph modification of the Thornton method. No particular correlation could be seen between the results by the rapid tests and the response to fertilizer treatments as measured by the greenhouse yields.

Rapid soil tests for potassium were made by three methods (Spurway, Morgan and Thornton) in the first year and by two of these (Spurway and Morgan) in the second year. The individual results, together with the response of the crops to applications of K, are given in Table 16. The tendency of all the methods is to give low readings. Out of 41 tests by the Spurway method, 34 were L or VL, with 5 reading M and 2 MH. By the Morgan method, 25 readings out of 29 were L or VL, with 2 giving M and 2 VH, while all 29 readings by the Thornton method were L or VL. By the Spurway method, 4 of the M and both MH readings were obtained on soils where no crop response to added potassium was obtained. To this extent, the rapid tests correlated with response to potash fertilization. The 2 VH readings by the Morgan method were on samples of Rideau clay which gave no response when potassium was added, but the other 2 Rideau clay samples gave low readings by this method. On this soil type, the response did not always correlate with the test.

SUMMARY AND CONCLUSIONS

Rapid soil tests for phosphorus and potassium have been made on 41 soil samples representing 11 of the main soil types of Carleton county. The methods used were those of Spurway, Morgan and Thornton, together with the Guelph modification of Thornton's procedure. The results of the tests were compared with the response obtained to fertilization by measuring the yields of crops (both cereals and legumes) grown in the greenhouse.

The different kinds of crops responded differently to the fertilizers used. In general, the cereals responded to nitrogen fertilization but the legumes did not; in one or two cases, a considerable decrease in the growth

of the legumes resulted from applying nitrogen to the soil. Both kinds of crops responded to phosphatic fertilization on all but the two soil types, with the legumes showing a greater response than the cereals. When potassium was applied to the soil, the cereals, except in one case, showed no response but, in 7 of the soils, a considerable increase in the yield of the legumes resulted.

Each of the rapid soil tests had a general tendency to give readings within a certain range regardless of the soil type. The Spurway method tended to give low readings for phosphorus; the Morgan and Thornton methods gave a very large proportion of medium to high readings; most of the readings by the Guelph modification were high or very high. When tests were made for potassium, readings by all three methods tended to be low.

The correlation between soil tests and crop yields was rather disappointing. Some of the difficulties in the way of interpretation have just been pointed out, i.e., the different response of cereals and legumes to the fertilizer elements applied, and the tendency for the methods to give values within certain ranges regardless of soil type. The application of rapid tests in the past has proved most useful when dealing with a single crop grown on closely related soil types and where a background of information regarding fertilizer response was available. This may continue to be the case for some considerable time. Any attempt to apply these methods on a variety of soil types, used for the growth of different crops, will be limited by the difficulties encountered in this investigation and perhaps by other difficulties as well. Their more general application will necessitate a rather careful calibration for each crop and for each soil type.

TABLE 1.—AREAS OF ELEVEN SOIL GROUPS OF CARLETON COUNTY

Soil types	Area (acres)	Per cent of total
Farmington loams, sandy loams, etc.	136,320	22.4
North Gower clay loam	76,160	12.5
Rideau clays	50,880	8.4
Grenville loams	43,520	7.3
Rubicon sand	35,200	5.8
Carp clay loam	22,720	3.8
Kars gravelly loam	22,200	3.7
Osgoode loam	21,440	3.5
Castor fine sandy loam	15,360	2.5
Uplands sand	13,120	2.2
Manotick sandy loam	9,280	1.5
	446,200	73.6

TABLE 2.—AVERAGE YIELDS* ON VARIOUS SOIL TYPES

Soil types	Barley grain	Clover dry yield	Oats grain	Alfalfa dry yield
Uplands sand	1.25	5.42	5.21	8.41
Rubicon sand	4.90	8.71	6.89	2.88
Kars gravelly loam	2.81	9.62	5.88	15.08
Manotick sandy loam	5.50	8.74	7.36	8.78
Castor fine sandy loam	4.35	8.02	8.37	8.58
Farmington loam	5.95	9.70	6.87	5.57
Grenville loam	7.98	6.95	9.26	11.48
Osgoode loam	8.46	13.23	12.08	11.30
Carp clay loam	8.02	12.61	8.97	9.95
North Gower clay	7.60	13.10	11.21	10.88
Rideau clay	12.33	15.66	11.30	18.54

* Grams per pot.

TABLE 3.—CROP RESPONSE IN GREENHOUSE AND RESULTS OF SOIL TESTS—UPLANDS SAND

Crop	Stewart					Lecuyer					
	% Soil N					% Soil N					
	% Increase due to N					% Increase due to N					
1941-42 Barley Clover	alone	with P	with K	with PK	Avg.	0.03	alone	with P	with K	with PK	Avg.
	+189 + 8	+482 - 20	—	+451 - 15	+374 - 9		—	—	—	—	—
	+178 - 37	+138 - 56	+160 - 22	+109 - 64	+146 - 45		+76 -55	+70 -42	+97 -43	+58 +26	+75 -29
1942-43 Oats Alfalfa	% Increase due to P					0.08	% Increase due to P				
	alone	with N	with K	with NK	Avg.		alone	with N	with K	with NK	Avg.
	-22 +47	+56 + 8	-12 +30	—	+ 7 +28		—	—	—	—	—
1942-43 Oats Alfalfa	+22 +42	+ 5 -13	+27 +66	+ 2 -23	+14 +18	Rapid Soil Tests*	Sp.	Mo.	Th.	Gu.	Ru.
	—	—	—	—	—		L	MII	VII	II	53
	—	—	—	—	—		VVL	L	—	—	80
1941-42 Barley Clover	% Increase due to K					Rapid soil tests*	% Increase due to K				
	alone	with N	with P	with NP	Avg.		alone	with N	with P	with NP	Avg.
	+2 +41	—	+16 +26	+ 9 +34	+ 9 +34		—	—	—	—	—
1942-43 Oats Alfalfa	+15 - 3	+ 7 +18	+19 +13	+ 4 - 8	+11 + 5	Rapid soil tests*	Sp.	Mo.	Th.	Gu.	Ru.
	—	—	—	—	—		L	VVL	—	—	—
	—	—	—	—	—		—	—	—	—	—

* Sp = Spurway
Mo = Morgan
Th = Thornton

Gu = Guelph
Ru = Ruhrke
% Ex = % Exchangeable

VII = very high
H = high
M = medium
L = low
VL = very low

* Sp = Spurway
Mo = Morgan
Th = Thornton

Gu = Guelph
Ru = Rühne
% Ex = % Exchangeable

VII = very high
II = high
M = medium

L = low
VL = very low

TABLE 4.—CROP RESPONSE IN GREENHOUSE AND RESULTS OF SOIL TESTS—RUBICON SAND

Crop	Saunders					Hawkins				
	% Increase due to N					% Increase due to N				
	alone	with P	with K	with PK	Avg.	alone	with P	with K	with PK	Avg.
1941-42 Barley Clover	+46	+67	—	+73	+62	+38	+67	—	+69	+58
	-7	23	—	+15	-5	+5	+2	—	+3	+3
										0.13
1942-43 Oats Alfalfa	+28	+1	+23	+47	+25	+52	-16	+89	+68	+48
	+1	+108	+22	-28	+26	+51	+42	+10	-16	+22
										0.16
	% Increase due to P					% Increase due to P				
	alone	with N	with K	with NK	Avg.	alone	with N	with K	with NK	Avg.
	Sp.	Mo.	Th.	Gu.	Ru.	Sp.	Mo.	Th.	Gu.	Ru.
1941-42 Barley Clover	+5	+19	0	—	+8	+16	+41	+14	—	+24
	+5	-13	-17	—	-8	+19	+15	+19	—	+18
										39
1942-43 Oats Alfalfa	+4	-17	-7	+11	-2	+11	-38	-2	-12	-10
	-9	+86	+46	-13	+28	-15	-21	+23	-5	-4
										128
	% Increase due to K					% Increase due to K				
	alone	with N	with P	with NP	Avg.	alone	with N	with P	with NP	Avg.
	Sp.	Mo.	Th.	% Ex.		Sp.	Mo.	Th.	% Ex.	
1941-42 Barley Clover	-4	—	-8	-5	-6	+14	—	+11	+13	+13
	+16	—	-8	+38	+15	+47	—	+47	+49	+48
										Trace
1942-43 Oats Alfalfa	+11	+7	-1	+44	+15	+26	+58	+12	+124	+55
	+69	+104	+172	-5	+85	+158	+88	+277	+125	+162
										0.009

* Sp = Spurway
Mo = Morgan
Th = Thornton

Gu = Guelph
Ru = Runkle
% Ex = % Exchangeable

VH = very high
H = high
M = medium

L = low
VL = very low

TABLE 5.—CROP RESPONSE IN GREENHOUSE AND RESULTS OF SOIL TESTS—KARS GRAVELLY LOAM

Crop	Redmond Bros.										McMenomy (1941-42), Lecuyer (1942-43)									
	% Increase due to N					% Soil N					% Increase due to N					% Soil N				
1941-42 Barley Clover	alone	with P	with K	with PK	Avg.	0.08					alone	with P	with K	with PK	Avg.	0.07				
	+133 - 5	+208 - 7	— —	+172 - 9	+171 - 7						+124 +11	+198 -17	— —	+171 -17	+164 - 8					
1942-43 Oats Alfalfa	+66 -17	+76 -27	+84 -28	+92 -12	+80 -21	0.10					+120 -31	+99 -42	+101 -24	+85 -33	+101 -33	0.15				
1941-42 Barley Clover	alone	with N	with K	with NK	Avg.	Rapid soil tests*					alone	with N	with K	with NK	Avg.	Rapid soil tests*				
	- 1 + 2	+31 0	+ 4 +21	— —	+11 + 8	Sp.	Mo.	Th.	Gu.	Ru.	-20 +26	+ 6 - 5	+ 9 + 9	— —	- 2 +10	Sp.	Mo.	Th.	Gu.	Ru.
1942-43 Oats Alfalfa	+ 2 + 9	+ 9 - 4	+ 7 - 4	+11 +17	+ 7 + 5	L	MH	—	—	84 —	+13 +19	+ 2 + 1	+10 +18	+ 1 + 4	+ 7 +11	L	M	H	H	46 —
																				283 —
1941-42 Barley Clover	alone	with N	with P	with NP	Avg.	Rapid soil tests*					alone	with N	with P	with NP	Avg.	Rapid soil tests*				
	+ 2 - 5	— —	+ 7 +12	- 6 +10	+ 1 + 6	Sp.	Mo.	Th.	% Ex.	Trace —	-20 +59	— —	+ 9 +37	0 +37	- 4 +44	Sp.	Mo.	Th.	% Ex.	0.004 —
1942-43 Oats Alfalfa	- 4 +32	+ 6 +15	0 +17	+ 9 +41	+ 3 +26	L	VVL	—	0.001 —	—	+ 1 +19	- 8 +31	- 1 +17	- 8 +36	- 4 +26	L	L	—	0.002 —	

L = low
VL = very low

VH = very high
H = high
M = medium

Sp = Spurway
Mo = Morgan
Th = Thornton

Gu = Guelph
Ru = Rubinke
% Ex = % Exchangeable

TABLE 6.—CROP RESPONSE IN GREENHOUSE AND RESULTS OF SOIL TESTS—MANOTICK SANDY LOAM

Crop	Lytile					McClure (1941-42) and Goodwin (1942-43)															
	% Increase due to N					% Soil N					% Increase due to N					% Soil N					
1941-42 Barley Clover	alone	with P	with K	with PK	Avg.	0.15															
	+33 - 5	+76 + 7	— —	+91 +14	+67 + 5															+16 + 6	+61 + 3
1942-43 Oats Alfalfa	+32 - 4	+45 0	+48 +21	+51 +16	+44 + 8	0.15															
1941-42 Barley Clover	alone	with N	with K	with NK	Avg.	Rapid soil tests					% Increase due to P					Rapid soil tests*					
	+ 7 +36	+41 +54	+ 1 +33	— —	+16 +41	Sp.	Mo.	Th.	Gu.	Ru.	alone	with N	with K	with NK	Avg.	Sp.	Mo.	Th.	Gu.	Ru.	
1942-43 Oats Alfalfa	+13 +72	+25 +79	+44 +97	+46 +90	+32 +85	L	M	—	—	222 —	- 1 +50	+38 +45	+ 9 +59	— —	+15 +51	— —	M —	M- —	M —	61 —	
											+22 -12	+ 7 -32	+14 +57	+17 + 4	+15 + 4	L —	L —	— —	— —	49 —	
1941-42 Barley Clover	alone	with N	with P	with NP	Avg.	Rapid soil tests*					% Increase due to K					Rapid soil tests*					
	+10 +17	— —	+ 4 +15	+13 +21	+ 9 +18	Sp.	Mo.	Th.	% Ex.	Sp.	Mo.	Th.	% Ex.	Sp.	Mo.	Th.	% Ex.	Sp.	Mo.	Th.	% Ex.
1942-43 Oats Alfalfa	-19 -20	- 9 0	+ 3 - 9	+ 7 + 6	- 5 - 6	L	L	—	—	0.013 —	- 3 + 4	— —	+ 6 +10	- 8 + 9	- 2 + 8	L —	— —	VL —	— —	0.006 —	0.004 —

* Sp = Spurway
Mo = Morgan
Th = Thornton

Gu = Guelph
Ru = Rühnkne
% Ex = % Exchangeable

VH = very high
H = high
M = medium

L = low
VL = very low

TABLE 7.—CROP RESPONSE IN GREENHOUSE AND RESULTS OF SOIL TESTS—CASTOR FINE SANDY LOAM

Crop	Waddell					Quaile				
	% Increase due to N					% Increase due to N				
	alone	with P	with K	with PK	Avg.	alone	with P	with K	with PK	Avg.
1941-42 Barley Clover	+4 +10	+84 -2	— —	+84 -14	+57 -2	+68 -9	+99 -6	— —	+118 +4	+95 -4
	0.20	0.21								
1942-43 Oats Alfalfa	-2 +7	+12 +5	-1 0	+24 -1	+11 +4	+39 -5	+53 -19	+55 -11	+41 -17	+47 -13
1941-42 Barley Clover	+35 +49	+140 +34	+46 +94	— —	+74 +59	— +230	— +46	+8 +51	— —	+10 +49
1942-43 Oats Alfalfa	+140 +256	+174 +250	+122 +226	+178 +223	+154 +239	213 —	+1 +33	+11 +14	+14 +7	+10 +18
1941-42 Barley Clover	-2 +16	— —	+5 +51	+5 +31	+3 +33	— L	-12 +35	— —	+3 +53	-5 +42
1942-43 Oats Alfalfa	+5 +37	+7 +27	-3 +25	+8 +17	+4 +27	VL —	-7 +22	+4 +14	-4 0	-1 +9

* Sp = Spurway
Mo = Morgan
Th = Thornton

Gu = Guelph
Ru = Ruhnke
% Ex = % Exchangeable

VH = very high
H = high
M = medium

L = low
VL = very low

TABLE 8.—CROP RESPONSE IN GREENHOUSE AND RESULTS OF SOIL TESTS—FARMINGTON LOAM

Crop	Featherstone					Fraser														
	% Increase due to N					% Soil N					% Increase due to N					% Soil N				
	alone	with N	with K	with PK	Avg.						alone	with P	with K	with PK	Avg.					
1941-42 Barley Clover	+55	+72	—	+69	+65	0.20					- 2	+37	—	+17	+17	0.26				
	+ 3	-10	—	-13	- 7		+13	- 2	—	-16	- 2									
1942-43 Oats Alfalfa	+16	+13	+ 3	+15	+12	0.34					+ 6	+33	0	+35	+19	0.31				
	-37	+ 8	-40	+ 2	-17		+ 7	-11	- 3	-15	- 6									
	% Increase due to P					Rapid soil tests*					% Increase due to P					Rapid soil tests*				
	alone	with N	with K	with NK	Avg.	Sp.	Mo.	Th.	Gu.	Ru.	alone	with N	with K	with NK	Avg.	Sp.	Mo.	Th.	Gu.	Ru.
1941-42 Barley Clover	-10	- 1	-11	—	- 7	L	MH	H	H	215	+51	+111	+70	—	+77	L	MH	M	H	268
	+ 8	- 5	+26	—	+10	—	—	—	—	—	+35	+17	+57	—	+36	—	—	—	—	—
1942-43 Oats Alfalfa	+136	+130	+132	+160	+140	L	L	—	—	156	+33	+66	+17	+57	+43	L	L	—	—	140
	+177	+377	+235	+465	+314	—	—	—	—	—	+103	+69	+154	+122	+112	—	—	—	—	—
	% Increase due to K					Rapid soil tests*					% Increase due to K					Rapid soil tests*				
	alone	with N	with P	with NP	Avg.	Sp.	Mo.	Th.	% Ex.		alone	with N	with P	with NP	Avg.	Sp.	Mo.	Th.	% Ex.	
1941-42 Barley Clover	+ 9	—	+ 9	+ 7	+ 8	L	—	—	0.003		+ 4	—	+17	0	+ 7	L	—	VL	0.003	
	+27	—	+48	+44	+40	—	—	—	—	—	+49	—	+74	+49	+57	—	—	—	—	—
1942-43 Oats Alfalfa	+ 2	-10	0	+ 2	- 2	L	VL	—	0.005		+15	+ 9	+ 1	+ 2	+ 7	L	VL	—	0.004	
	+ 2	- 3	+23	+15	+ 9	—	—	—	—	—	+ 5	- 4	+31	+26	+15	—	—	—	—	—

L = low
VL = very lowVH = very high
H = high
M = mediumGu = Guelph
Ru = Ruhnke
% Ex = % Exchangeable* Sp = Spurway
Mo = Morgan
Th = Thornton

TABLE 9.—CROP RESPONSE IN GREENHOUSE AND RESULTS OF SOIL TESTS—GRENVILLE LOAM

Crop	Dow					Stewart				
	% Increase due to N					% Increase due to N				
	alone	with P	with K	with PK	Avg.	alone	with P	with K	with PK	Avg.
1941-42 Barley Clover	+9 +9	+38 +9	— —	+41 +4	+29 +7	0.29	— —	— —	— —	— —
1942-43 Oats Alfalfa	+1 +16	+53 +9	-6 +5	+29 -16	+26 +4	0.29	+41 -31	+39 -9	+47 -3	+41 -17
	% Increase due to P					% Increase due to P				
	alone	with N	with K	with NK	Avg.	alone	with N	with K	with NK	Avg.
1941-42 Barley Clover	+26 +89	+60 +90	+11 +48	— —	+32 +76	92	— —	— —	— —	— —
1942-43 Oats Alfalfa	+33 +102	+103 +90	+53 +151	+110 +101	+100 +111	77	-1 +30	-2 +72	-5 +12	-5 +40
	% Increase due to K					% Increase due to K				
	alone	with N	with P	with NP	Avg.	alone	with N	with P	with NP	Avg.
1941-42 Barley Clover	+12 +46	— —	-1 +14	+1 +8	+4 +23	0.004	— —	— —	— —	— —
1942-43 Oats Alfalfa	+8 +3	0 -7	+24 +28	+4 -1	+9 +6	0.026	+4 +13	+1 +23	-2 +3	-1 +9
	Rapid soil tests*					Rapid soil tests*				
	Sp.	Mo.	Th.	Gu.	Ru.	Sp.	Mo.	Th.	Gu.	Ru.
1941-42 Barley Clover	— —	M —	H —	II —	92 —	— —	— —	— —	— —	— —
1942-43 Oats Alfalfa	L —	LM —	— —	— —	77 —	— —	L —	MH —	— —	121 —
	Rapid soil tests*					Rapid soil tests*				
	Sp.	Mo.	Th.	Gu.	% Ex.	Sp.	Mo.	Th.	Gu.	% Ex.
1941-42 Barley Clover	L —	— —	VL —	— —	0.004 —	— —	— —	— —	— —	— —
1942-43 Oats Alfalfa	L —	L —	— —	— —	0.026 —	— —	L —	M —	— —	0.030 —

* Sp = Spurway
Mo = Morgan
Th = Thornton

Gu = Guelph
Ru = Ruhnke
% Ex = % Exchangeable

VH = very high
H = high
M = medium

L = low
VL = very low

TABLE 10.—CROP RESPONSE IN GREENHOUSE AND RESULTS OF SOIL TESTS—OSGOODE LOAM

Crop	Brown						Nixon					
	% Increase due to N						% Increase due to N					
	alone	with P	with K	with PK	Avg.	% Soil N	alone	with P	with K	with PK	Avg.	% Soil N
1941-42 Barley Clover	+34	+62	—	+79	+58	0.20	+33	+41	—	+33	+36	0.21
	-14	+15	—	-2	0		+8	+23	—	-4	+9	
	+35	+39	+26	+55	+39	0.15	+19	+22	+21	+15	+19	0.45
1942-43 Oats Alfalfa	+6	+20	+3	-1	+7		+5	-9	-6	-16	-9	
	% Increase due to P						% Increase due to P					
	alone	with N	with K	with NK	Avg.	Rapid soil tests*	alone	with N	with K	with NK	Avg.	Rapid soil tests*
	Sp.	Mo.	Th.	Gu.	Ru.		Sp.	Mo.	Th.	Gu.	Ru.	
1941-42 Barley Clover	+11	+34	-10	—	+12		+7	+13	+18	—	+13	
	+22	+62	+70	—	+51		+11	+26	+15	—	+17	
1942-43 Oats Alfalfa	+76	+81	+43	+76	+69		+8	+11	+8	+3	+8	
	+46	+67	+115	+117	+86		+24	+7	+19	-7	+14	
	% Increase due to K						% Increase due to K					
	alone	with N	with P	with NP	Avg.	% Ex.	alone	with N	with P	with NP	Avg.	% Ex.
	Sp.	Mo.	Th.	% Ex.			Sp.	Mo.	Th.	% Ex.		
1941-42 Barley Clover	+4	-13	-33	-4	-4		-7	—	+2	-4	-3	
	-5	+33	+8	+12	+12	0.005	+14	—	+19	-7	+9	0.005
1942-43 Oats Alfalfa	+2	-5	-17	-8	-7		+1	+2	+1	-5	0	
	+41	+38	+108	+71	+65	0.002	+20	+7	+15	+7	+12	0.004

*Sp = Spurway
Mo = Morgan
Th = Thornton
Gu = Guelph
Ru = Runkle
% Ex = % Exchangeable
VH = very high
H = high
M = medium
L = low
VL = very low

TABLE 11.—CROP RESPONSE IN GREENHOUSE AND RESULTS OF SOIL TESTS—CARP CLAY LOAM

Crop	Ellis & Shaw						Hudson					
	% Increase due to N						% Increase due to N					
	alone	with N	with P	with K	with PK	Avg.	alone	with N	with P	with K	with PK	Avg.
1941-42 Barley Clover	+43	+59	-2	—	+87	+63	—	—	—	—	—	—
	+10	—	—	—	+6	+5	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—
1942-43 Oats Alfalfa	+25	+37	-3	+29	+38	+32	0.45	+64	+27	+7	+66	+41
	-23	—	—	-10	+13	-6	—	-22	-4	-5	-17	+12
	—	—	—	—	—	—	—	—	—	—	—	—
	% Increase due to P						% Increase due to P					
	alone	with N	with P	with K	with PK	Avg.	alone	with N	with P	with K	with PK	Avg.
	—	—	—	—	—	—	—	—	—	—	—	—
1941-42 Barley Clover	-2	+9	+20	+33	—	-1	—	—	—	—	—	—
	+34	—	—	—	—	+29	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—
1942-43 Oats Alfalfa	-4	+6	+100	+75	+8	+3	—	+60	+23	+26	+96	+51
	+60	—	—	+120	+120	+90	—	+126	+177	+203	+166	+168
	—	—	—	—	—	—	—	—	—	—	—	—
	% Increase due to K						% Increase due to K					
	alone	with N	with P	with K	with PK	Avg.	alone	with N	with P	with K	with PK	Avg.
	—	—	—	—	—	—	—	—	—	—	—	—
1941-42 Barley Clover	+2	—	-5	+12	-1	+3	—	—	—	—	—	—
	-8	—	-9	-1	-6	-6	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—
1942-43 Oats Alfalfa	-6	-3	-1	-1	-1	-3	—	-18	-3	-1	0	-6
	-7	+8	+1	+19	+19	+5	—	+4	+6	+15	+22	+12
	—	—	—	—	—	—	—	—	—	—	—	—
	Rapid soil tests *						Rapid soil tests *					
	Sp.	Mo.	Th.	Gu.	Ru.	% Ex.	Sp.	Mo.	Th.	Gu.	Ru.	% Ex.
	—	—	—	—	—	—	—	—	—	—	—	—
1941-42 Barley Clover	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—
1942-43 Oats Alfalfa	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—
1941-42 Barley Clover	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—
1942-43 Oats Alfalfa	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—

L = low
VL = very lowVH = very high
H = high
M = mediumGu = Guelph
Ru = Rulmke
% Ex = % Exchangeable* Sp = Spurway
Mo = Morgan
Th = Thornton

TABLE 12.—CROP RESPONSE IN GREENHOUSE AND RESULTS OF SOIL TESTS—NORTH GOWER CLAY

Crop	Argue					Kenny									
	% Increase due to N					% Increase due to N					% Soil N				
	alone	with P	with K	with PK	Avg.	alone	with P	with K	with PK	Avg.	alone	with P	with K	with PK	% Soil N
1941-42 Barley Clover	+26	+63	—	+62.	+50	+25	+61	—	+61	+49	0.24	+16	+5	+3	0.24
	+17	— 1	—	— 9	+ 2	+16	—	—	—	+ 8					
1942-43 Oats Alfalfa	+34	+58	+20	+54	+42	+17	+32	+42	+37	+32	0.21	+17	+32	+37	0.21
	—11	—14	+ 5	— 2	— 6	— 8	—11	+ 4	— 7	— 6					
1941-42 Barley Clover	+ 5	+36	+11	—	+17	+24	+60	+10	—	+31		+24	+60	—	
	+54	+31	+61	—	+49	+50	+36	+70	—	+52		+50	+70	—	
1942-43 Oats Alfalfa	+34	+58	+26	+61	+45	+ 2	+15	0	— 3	+ 4		+ 2	+15	—	
	+194	+186	+154	+136	+168	+34	+31	+55	+39	+40		+34	+31	—	
1941-42 Barley Clover	— 2	—	+ 3	+ 3	+ 1	+11	—	— 2	— 1	+ 3		+11	— 2	—	
	+10	—	+14	+ 4	+ 9	— 4	—	+ 9	+ 7	+ 4		— 4	+ 9	—	
1942-43 Oats Alfalfa	+ 2	— 8	— 4	— 6	— 4	— 9	+11	—11	— 7	— 4		— 9	+11	— 7	
	+ 2	+20	—12	0	+ 3	— 2	+11	+13	+18	+10		— 2	+11	+18	

* Sp = Spurway
Mo = Morgan
Th = Thornton

Gu = Guelph
Ru = Ruhnke
% Ex = % Exchangeable

VH = very high
H = high
M = medium

L = low
VL = very low

TABLE 13.—CROP RESPONSE IN GREENHOUSE AND RESULTS OF SOIL TESTS—RIDEAU CLAY

Crop	Rowe					Kennedy				
	% Increase due to N					% Increase due to N				
	alone	with P	with K	with PK	Avg.	alone	with P	with K	with PK	Avg.
1941-42 Barley Clover	+53 +20	+62 +4	— —	+77 +19	+64 +14	-15 -21	+42 +6	— —	+30 +5	+19 -3
	0.23 —									0.33 —
1942-43 Oats Alfalfa	+47 -12	+43 -22	+46 -19	+67 -11	+51 -16	+43 -14	+48 -6	+35 -3	+54 -23	+45 -12
	0.20 —									0.34 —
	% Increase due to P					% Increase due to P				
	alone	with N	with K	with NK	Avg.	alone	with N	with K	with NK	Avg.
1941-42 Barley Clover	+20 +62	+27 +41	-3 +25	— —	+15 +43	-4 -3	+61 +30	+37 -1	— —	+31 +9
	— —	— —	— —	— —	— —	— —	— —	— —	— —	— —
1942-43 Oats Alfalfa	+20 +31	+17 +16	+3 +34	+18 +48	+15 +32	0 +31	+3 +44	-1 +50	+12 +20	+4 +36
	— —	— —	— —	— —	— —	— —	— —	— —	— —	— —
	% Increase due to K					% Increase due to K				
	alone	with N	with P	with NP	Avg.	alone	with N	with P	with NP	Avg.
1941-42 Barley Clover	+12 +29	— —	-10 -1	-1 +13	0 +14	-34 -10	— —	-6 -9	-14 -10	-18 -10
	— —	— —	— —	— —	— —	— —	— —	— —	— —	— —
1942-43 Oats Alfalfa	+3 -11	+2 -18	-12 -5	+3 +4	-1 -9	0 -6	-6 +6	-2 +8	+2 -11	-2 -1
	— —	— —	— —	— —	— —	— —	— —	— —	— —	— —
	Rapid soil tests*					Rapid soil tests*				
	Sp.	Mo.	Th.	Gu.	Ru.	Sp.	Mo.	Th.	Gu.	Ru.
1941-42 Barley Clover	— —	— —	— —	— —	— —	— —	— —	— —	— —	— —
	— —	— —	— —	— —	— —	— —	— —	— —	— —	— —
1942-43 Oats Alfalfa	VVL —	L —	— —	— —	364 —	VVL —	L —	— —	— —	323 —
	— —	— —	— —	— —	— —	— —	— —	— —	— —	— —
	Rapid soil tests*					Rapid soil tests*				
	Sp.	Mo.	Th.	Gu.	Ex.	Sp.	Mo.	Th.	Gu.	Ex.
1941-42 Barley Clover	M —	L —	L —	— —	0.032 —	M —	L —	L —	— —	0.026 —
	— —	— —	— —	— —	— —	— —	— —	— —	— —	— —
1942-43 Oats Alfalfa	MH —	VH —	— —	— —	0.045 —	MH —	VH —	— —	— —	0.037 —
	— —	— —	— —	— —	— —	— —	— —	— —	— —	— —

* Sp = Spurway
Mo = Morgan
Th = Thornton
G = Guelph
Ru = Rulnick
% Ex = % Exchangeable

VH = very high
H = high
M = medium

L = low
VL = very low

TABLE 14.—AVERAGE PERCENTAGE INCREASE OF CEREALS AND LEGUMES DUE TO APPLICATION OF N, P AND K

Nitrogen			Phosphorus			Potassium		
Cereals		Legumes	Cereals		Legumes	Cereals		Legumes
Uplands 198	Rubicon	12	Farmington 63	Farmington 118	Rubicon 19	Rubicon	78	
Kars 129	Carp	4	Castor 62	Carp 96	Uplands 9	Farmington	30	
Manotick 55	Manotick 4		Grenville 42	Castor 91	Farmington 5	Castor	28	
Castor 53	Osgoode 2		Osgoode 26	North Gower 77	Grenville 4	Manotick	26	
Rubicon 48	North Gower -1		North Gower 24	Grenville 57	Manotick 1	Kars	25	
Carp 45	Grenville -2		Manotick 20	Manotick 45	Castor 0	Osgoode	25	
Rideau 45	Castor -4		Carp 18	Osgoode 42	Kars -1	Uplands	24	
North Gower 43	Rideau -4		Uplands 17	Rideau 30	North Gower -1	Grenville	10	
Osgoode 38	Farmington -8		Rideau 16	Uplands 19	Carp -2	North Gower	7	
Grenville 32	Kars -17		Kars 6	Kars 9	Osgoode -4	Carp	4	
Farmington 28	Uplands -28		Rubicon 5	Rubicon 8	Rideau -5	Rideau	-2	

TABLE 15.—INDIVIDUAL RESULTS OF RAPID SOIL TESTS FOR PHOSPHORUS AND RESPONSE TO PHOSPHATIC FERTILIZERS

Soil types	Average response		Spurway	Morgan	Thornton	Guelph
	Cereals	Legumes				
	%	%				
Farmington	63	118	L L L L	MH MH L L	II M	H H
Castor	62	91	L L VVL L	MH H L MH	M H	M VH
Grenville	42	57	L L	M LM MH	H	H
Osgoode	26	42	M M L M	H MH M M	M M	H H
North Gower	24	77	L VVL L	M M M M	M H	H VH
Manotick	20	45	L L	M M M L	M- M-	M M
Carp	18	96	L L VVL	MH MH LM	H	VH
Uplands	17	19	L VVL VL	MH L M	VH	H
Rideau	16	30	VVL VVL	MH MH L M	II H	VH VH
Kars	6	9	L L L L	MH M M MH	VH H	H H
Rubicon	5	8	L L VL L	MH MH M M	M L	II H

TABLE 16.—INDIVIDUAL RESULTS OF RAPID SOIL TESTS FOR POSTASSIUM AND RESPONSE TO POTASH FERTILIZER

Soil type	Average response		Spurway	Morgan	Thornton
	Cereals	Legumes			
	%	%			
Rubicon	19	78	L L VL L	VL VL M VL	VL VL
Uplands	9	24	L L L L	VL VL VL VL	VL
Farmington	5	30	L L L L	VL VL VL VL	VL VL
Grenville	4	10	L L L L	L M	VL
Manotick	1	26	L L L L	L VL	VL VL
Castor	0	28	L L L L	VL VL	L- VL
Kars	-1	25	L L L L	VVL VL VL L	VL L
North Gower	-1	7	L L M L	L L	VL VL
Carp	-2	4	L M L	L VL	L
Osgoode	-4	25	L L L M	VL L	VL L
Rideau	-5	-2	M M MH MH	L L MH MH	L L

A DECIMAL SYSTEM FOR THE CLASSIFICATION AND MAPPING OF ONTARIO SOILS¹

G. A. HILLS²

The most satisfactory system of soil classification is one in which provision is made for the many properties which characterize the soil profile³. In view of the large number of properties possessed by each soil body, and the way in which these vary from one soil to another, it would seem that such a classification would be practically impossible. However, it has been found that most properties can be arbitrarily placed in one of a few groups, each group reflecting some soil-forming factor or factors. Since most of the separations in the field must be based on physical properties, largely those which can be detected by the eye, the basis of field classification is largely outlined in terms of such properties. Associated with these are many other properties which can be determined only in the laboratory by chemical, physical and biological analyses. It cannot be too strongly emphasized that such groupings cannot be made on other than a philosophical basis. For example, in no other way is it possible to separate all the features of a soil profile which reflect the influence of geologic material from those features which indicate the effect of climate, vegetation and ground water.

In order to classify soils and map their distribution, there are required two schemes of classification, namely, the taxonomic and the chorologic. Taxonomic soil classification is concerned with breaking the soil into units which will fit into a logical scientific scheme. Such a scheme does not, by itself, serve for mapping purposes because soils are not distributed according to any taxonomic sequence. When a taxonomic scheme has been established on a theoretical but logical basis, certain "type" units can then be chosen as measuring sticks. The chorologic or mapping system is one of convenience for recording the distribution pattern of taxonomic units through the use of the "type" profiles.

THE DECIMAL SYMBOL FOR TAXONOMIC UNITS⁴

In order to provide as simple a scheme as possible for the orderly examination of soil profiles, the soil characteristics have been separated arbitrarily into four groups. The variations within each group are indicated by a symbol, either a figure or a letter. The symbols of the four groups together form a decimal symbol, each group occupying a definite position as indicated in Table 1.

¹ Presented before a meeting of the Soils Group of the Canadian Society of Technical Agriculturists, Toronto, Ontario, June 27-29, 1944.

² Formerly Dominion Soil Surveyor in Ontario, now with the Provincial Department of Lands and Forests, Toronto, Ont.

³ The soil profile consists of a series of horizontal layers or horizons formed near the surface of the earth through the action of climate and living organisms upon the geological parent material. The individuality of soils can be noted by examining differences which occur along a vertical line drawn from points on the earth's surface toward its interior. A classification, based on soil profile, has been considered a genetic system since it shows differences and similarities of features which reflect the factors of soil formation. It must be remembered, however, that it is the characteristics of the profile, and not the factors of soil formation, which are classified. For the purpose of this paper, it was felt that an extensive bibliography was unnecessary. To those unfamiliar with this concept of soils, Dr. Kellogg's book, *The Soils that Support Us*, will prove most useful.

⁴ Other decimal schemes of soil classification in use in America have been found useful in giving direction to, or in making comparisons with, the one outlined in this paper (1, 2, 9).

TABLE 1.—KEY TO DIGITS IN THE DECIMAL SYMBOL

	0	0	0	0
<i>Thousands Digit</i>				
Characteristics reflecting the regional climate and associated vegetation.....				
<i>Hundreds Digit</i>				
Characteristics reflecting the "fabric" of the geological parent material.....				
<i>Tens Digit</i>				
Characteristics reflecting the petrographic nature of the geological parent material.....				
<i>Units Digit</i>				
Characteristics reflecting the local environment factors, other than geological material.....				

Each group of characteristics is subdivided on an arbitrary basis into major divisions. In order that these subdivisions be represented by numerals in the symbol, it is convenient to have not more than ten. Where it is necessary to have more, letters and other devices may be used. Since any subdivision of one group may combine with any one of the subdivisions of the other groups, a large number of combinations is theoretically possible. This number is further increased when combinations of types or transitions are recognized. Fortunately, however, only a few of the many possible combinations occur over a significant area in any one region.

The arrangement of the groups within the compound symbol is one of convenience for field classification. If the regional soil types (indicated by the thousands digit) have not been established previously, the soil surveyor decides these tentatively upon a precursory examination of the soil profiles on the well-drained locations, aided by a knowledge of the natural vegetation. As will be shown later, the final decision regarding soil regions can be made only after the local variations have been studied in detail⁵. Frequently all the soils within a mapping area belong to the same regional type so that this digit may be conveniently omitted on the map. An experienced surveyor will gain much information concerning the geological structure or fabric of the parent materials (hundreds column) by noting the topographical form of the landscape. For instance, he knows that the materials dominant in the ridges and basins of a terminal moraine are coarse, open, and stony, while those of a former lake-bed are more compact and stonefree. Information verifying these observations is obtained by examining the soil profiles in road-cuts and pits. Inspection of the rock fragments occurring in these profiles also aids him in determining the petrographical type of the parent material (the tens column). He next examines the range of local profile variations on each type of parent material which he records in the units column. These local variations must be

⁵ Because a knowledge of local variations is basic to the discussion of regional types, these are discussed in this order and not as they occur in the mapping symbol.

properly correlated with all other variations within the same climatic region and the relationship established between them and local variations in adjoining regions.

THE STRUCTURAL TYPE OR FABRIC OF THE GEOLOGICAL PARENT MATERIALS*

The figures in the hundreds column of the decimal symbol indicate those features of the soil profile which reflect the structural type or fabric of the parent geologic material. They apply not only to the slightly weathered or unweathered materials immediately underlying the solum but also, as far as can be ascertained, to the original parent materials from which the solum has weathered, and as the latter may differ from the underlying, slightly weathered material, these are often difficult to determine. However, efforts are made to do this as fully as possible. The structural type or fabric refers to the nature of the physical elements of the soil skeleton and the proportion and arrangement of their individual particles within the geologic matrix. This includes the texture of the materials composing the fine skeleton, the type of sorting, compaction of materials, etc., all of which reflect the mode of deposition.

Table 2 outlines the main divisions.

TABLE 2.—KEY TO THE GEOLOGIC FABRIC (STRUCTURE) OF PARENT SOIL

0. Thin drift.
1. Coarse-textured open till.
2. Loamy till.
3. Heavy till.
4. Roughly stratified gravelly drift.
5. Uniformly stratified gravelly drift.
6. Heavy deep-water deposits.
7. Loamy deep-water deposits.
8. Roughly stratified sandy drift.
9. Uniformly stratified sandy drift.
- a. Alluvial drift.
- l. Loess deposits.
- m. Muck deposits.
- p. Peat deposits.
- r. Residual drift.
- etc.

Thin Drift (0 in the hundreds column)

This is the type found on deposits of varying texture which form but a shallow covering over bedrock. In a few instances they have weathered directly from the underlying bedrock (residual), but generally they have been deposited by ice, wind, or water. They are frequently stony regardless of the mode of deposition.

Coarse-Textured Till (1 in the hundreds column)

These are unassorted stony materials. The finer materials are usually a sandy loam in texture but loams are included where these are found in an open stony soil. This type is commonly associated with terminal and recessional moraines.

* For unfamiliar geological terms the reader is referred to texts on surface geology (7).

Loamy Till (2 in the hundreds column)

These are unassorted stony materials which are less open than the preceding type. Included in this type are light loams and sandy loams in which the stones are comparatively few and small in size. This also includes stonier soils in which the coarseness of the stony structure is modified by the compactness and heaviness of the materials between the stones. This type is commonly associated with ground moraines, frequently drumlinoid in nature. Some water-laid recessional moraines are also characterized by this type of material.

Heavy Till (3 in the hundreds column)

These are heavy soils in which fine grit and larger stones have but little effect on the porosity of the soil. The textural classes include clays, silty clays, and clay loams. In most cases they show little structure (unassorted), but there are occasional laminations due to ice pressure. This type of material is common in water-laid recessional moraines and in ground moraines. Much of the heavy till has originated from lake-laid deposits eroded by a readvance of the ice.

Roughly Stratified Gravelly Drift (4 in the hundreds column)

These are roughly-sorted gravels and coarse sands. The gravels are poorly rounded and, on the whole, are much more stony than in the deltaic deposits described below. Ice-rafted stones are common. These materials are common in eskers, kames, kame moraines, and in some beach formations. There are eroded and slumped edges of gravel terraces and deltas included in these types.

Uniformly Stratified Gravelly Drift (5 in the hundreds column)

These are uniformly sorted gravels commonly associated with deltas and terraces, which are generally uniformly bedded. The gravels are usually well-rounded and angular stones are uncommon. Heavy materials, if present, are in strata rather than comprising part of an unassorted matrix as in glacio-fluvial gravels described in No. 4.

Heavy Deep-water Deposits (6 in the hundreds column)

These are uniformly sorted and laminated clays, silty clays, and clay loams, associated with glacial lakes, marine seas and bays. Many of the glacial lake deposits show evidence of varving⁷. Marine deposits and very heavy lake-laid clays appear massive wherever the layering is difficult to detect because of uniform texture and colour.

Loamy Deep-water Deposits (7 in the hundreds column)

These are uniformly sorted and laminated loams, silt loams and fine sandy loams associated with glacial lakes and marine seas and bays. Layering and varving are common but there are also many deposits which can be identified as lacustrine only because of their stone-free nature.

⁷ A "varve" is the annual deposition in a glacial lake consisting of two clayey layers, one of which having a higher content of silt or fine sand.

Roughly Stratified Sandy Drift (8 in the hundreds column)

These are roughly-sorted sands, loamy sands and sandy loams commonly associated with esker, kames, interlobate moraines and dunes. Where necessary, this group may be subdivided on the basis of wind and water deposition.

Alluvial Drift (a in the hundreds column)

These are materials of variable texture, often with marked changes within short vertical and horizontal distances. They are frequently laminated with a fairly high percentage of organic matter between the layers. Contortions of the laminations occasionally occur. This type of material is commonly associated with recent stream deposits.

Muck Deposits (m in the hundreds column)

These are accumulations of organic remains (plants and animals) which have been decomposed to the extent that their original form is not recognizable. They have also been mineralized to a large extent either by the infiltration of sand, silt or clay, or by the release of minerals contained in the organic matter previous to its decomposition.

Peat Deposits (p in the hundreds column)

These are accumulations of organic remains (plants and animals) which have not been decomposed to the extent that their original form cannot be recognized.

PETROGRAPHIC TYPES OF GEOLOGIC MATERIALS

The figures in the tens column of the decimal symbol indicate the types of geologic materials according to the chemical composition of the rocks from which they are derived. While in some materials, other groups of elements are also important in soil development, the ten major divisions have been made on the proportionate content of silica, carbonate and clayey material. To these groups the terms siliceous, calcareous and argillaceous have been given in much the same sense as applied by Merrill (6) to stratified rocks, but have been extended to include similar materials occurring in any proportion in unconsolidated drift.

A. Calcareous Materials

Calcareous materials are characterized, in the main, by the content of calcium and magnesium carbonate. Rocks with a high percentage of carbonate are the limestones, dolomites and marbles. Many of the eruptive rocks such as diabase, and basalt, etc., yield small percentages of basic material upon weathering. The function of limy materials in soil development through the precipitation of colloidal sols has been widely discussed (4).

B. Siliceous Materials

These are silica-bearing materials which do not readily produce colloidal material upon weathering. The silicate-bearing rocks such as shale and slate are therefore placed in a separate group. Rocks rich in siliceous

materials are gneiss, granite, sandstones, etc. These materials take little active part in soil development under Ontario conditions as they neither readily produce colloids nor perform any function in their translocation and precipitation. They function passively in permitting freedom of movement within the weathered profile.

C. *Argillaceous Materials*

Included in this group are those materials which readily yield colloids under the weathering conditions prevailing in Ontario. They are mainly derived from shales and slates. These materials furnish the chief elements functioning in all soil forming processes.

As most of the geologic materials upon which the Ontario Soils are formed, are transported rather than residual, the parent soil materials are commonly of mixed origin. It has, therefore, been necessary to establish, arbitrarily, ten subdivisions which contain increasingly proportionate amounts of each of the three types of materials. The arrangement of these "focal points" of petrographical composition is diagrammatically indicated by the isosceles triangle method used in mechanical analysis of soils (See Figure 1 and Table 4). No quantitative determinations have been devised to determine the position of materials within the graph. Its use is confined, at present, to indicate trends observed by field inspection.

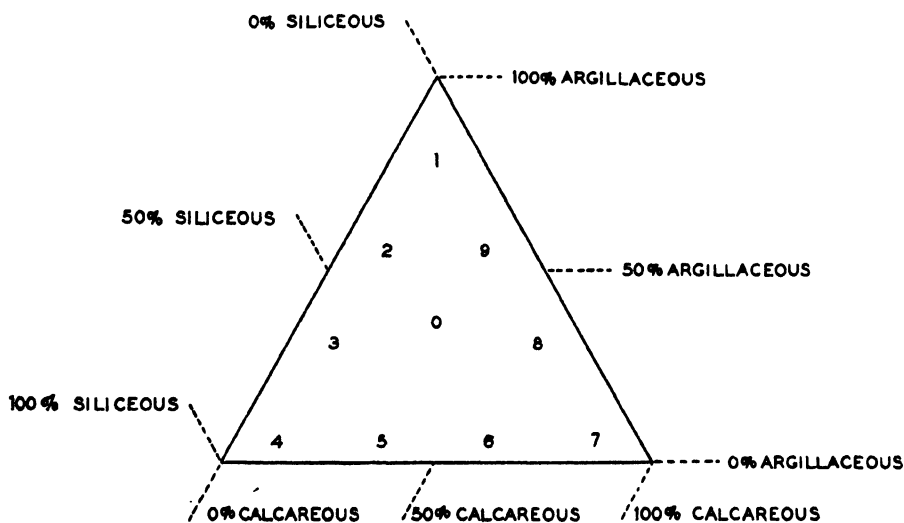


FIGURE 1. Diagram Showing Petrographical Type of Parent Material.

MAJOR PROFILE CLASSES

The units column of the decimal symbol is used to indicate local variations in soil profile, that is, those occurring within a climatic soil region. While such variations reflect all of the local environmental or soil-forming factors, major profile classes may be established which are based, in a large part, on characteristics which reflect the local climate and associated vegetation as conditioned by geologic materials and soil water. Within each major profile class there will be minor variations in the profile due to differences in the parent geologic materials, for which provision has been

made in the two preceding sections. The major profile classes are based on differences in the number, kind, and depth of the soil horizons within the profile. These horizons may differ in many ways, e.g., in structure, texture, colour, organic matter content, reaction, etc., such differences indicating not only kind, but also degree of development. A logical arrangement would appear to be a scale based on the degree to which soil development is controlled by local climate particularly soil moisture.

Within each climatic soil region there is a range of profile development with differences depending upon the degree to which climatic factors have been assisted or retarded by other soil forming factors. The maximum balanced development of an A-B profile is produced by that combination of soil-forming factors which permit the rainfall and temperature to exert their greatest combined influence. Under these conditions in Ontario, the development of the zone of eluviation⁸ (A horizons) and the zone of illuviation⁹ (B horizons) will be relatively proportionate or normal. Where the coincidence of soil forming factors permit the dominance of either temperature or moisture, a weak or disproportionate development takes place.

For convenience in classification, the generalized soil profiles common to a climatic soil region are diagrammatically arranged on a scale according to the type of development (see Figure 2). The juxtaposition is determined by the degree to which the moisture factor has been conditioned

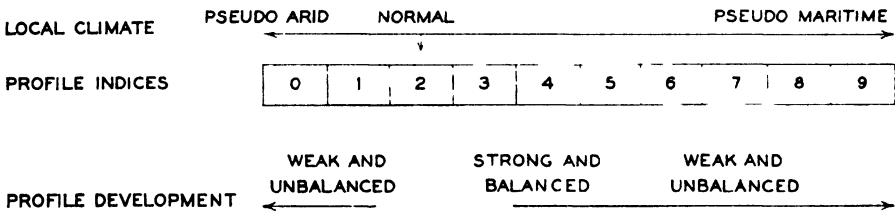


FIGURE 2. Major Profile Classes in Relation to Climate.

by other soil forming processes. At the extreme left are the soils developed under a coincidence of soil forming factors in which the influence of soil moisture is at a minimum. This results in what Penck called a "pseudo-arid local climate". Ellis has termed this the "oromorph site"(3). At the right are representatives of soils formed under the maximum influence of soil moisture within the region. Here exists what might be termed a pseudo-maritime climate, the hydromorphic condition as described by Ellis (3). The entire range has been divided into ten on an arbitrary and absolute basis and the divisions are indicated by indices 0-9.

The normal expression of both temperature and moisture for the region occurs at index 2, a condition defined by Ellis as "phytomorphic" (3). At this point the profile development is strong and balanced. Proceeding in either direction, the profiles become increasingly abnormal, either in point of weakness or unbalance. At the left (Index 0) there is little, if any, soil development and practically no soil moisture with the result that the

⁸ Eluviation refers to the "outgoing" of iron, aluminum, etc. from the upper or A horizons.

⁹ Illuviation refers to the incoming of iron, aluminum, etc. to the lower horizons (largely the B).

"soil" is little more than slightly weathered geologic materials and is therefore lithologic in nature. On the right (Index 9) the water factor becomes dominant to such an extent that the soils are practically hydrologic.

CLASSES SHOWING LESSER INFLUENCE OF SOIL MOISTURE

Soil profiles with indices occurring to the left of No. 2 in the profile scale reflect an increasingly lesser influence of soil moisture. Coincident with this is a greater variation in soil temperature. It is difficult to single out any one factor responsible for an abnormal profile development through a reduction in the effectiveness of rainfall. However, certain features may be mentioned which play an important part.

Steepness of Slope

This may cause a weak and/or truncated¹⁰ profile in three ways.

(a) By merely reducing the amount of water percolating through the soil as a result of run-off and of greater evaporation due to exposure to wind. This results in a weak, but not necessarily an unbalanced, soil profile.

(b) By gradual removal, through normal erosion, of the leached materials while those in the leachate are permitted to accumulate in the B horizon. The results is a profile with all horizons present, but with the A more greatly reduced than the B.

(c) By the rapid removal through accelerated erosion of the upper portion of a profile already developed. Any or all the soil horizons may be affected.

Nature of Geologic Material

(a) Coarse open siliceous materials. These reduce the effectiveness of rainfall on account of the more variable soil temperature, more rapid percolation and scantier vegetation. These conditions result in a deep leached horizon, a B horizon either very thin or absent, and frequently a wide B₃ horizon.

(b) Materials with high carbonate content. These result in the formation of thin profiles. All the horizons are generally present though they are frequently very thin. In extreme cases, the only horizon which can be easily discerned is the surface, high in organic matter. Such soils are more droughty than the normal soils. (Profile Scales do not show this type of development.)

(c) Shallow materials over bedrock. Evaporation losses are high from shallow soil materials on account of low moisture holding capacity. The depth of soil profile may also be limited by the depth of unconsolidated material over the bedrock. The profile may be weak with all horizons present, or in some cases merely consist of a surface organic layer overlying a partially weathered parent material.

Time

On well-drained materials which have been exposed comparatively recently by erosion or deposition the profile may be abnormal (absent in extreme cases) due to the relatively short period of weathering.

¹⁰ A weak profile is one in which all the horizons are developed to a small degree. A truncated profile is one in which the lower horizons exhibit a much stronger development than the upper, which may be entirely lacking.

CLASSES SHOWING GREATER INFLUENCE OF SOIL MOISTURE

Soil profiles with indices occurring to the right of No. 2 in the profile scale reflect an increasingly greater influence of soil moisture. This increase in the influence of moisture is reflected in a number of ways. The layer of organic accumulation increases in depth and decreases in stage of decomposition. The eluviated horizon due to acid leaching becomes shallower and changes to a deeper horizon of alkaline leaching. The B horizon likewise undergoes a change. First there is a greater tendency for the formation of a pan condition in heavy materials and for iron concretions to become common in the lighter materials. In the heavier soils the B horizon is

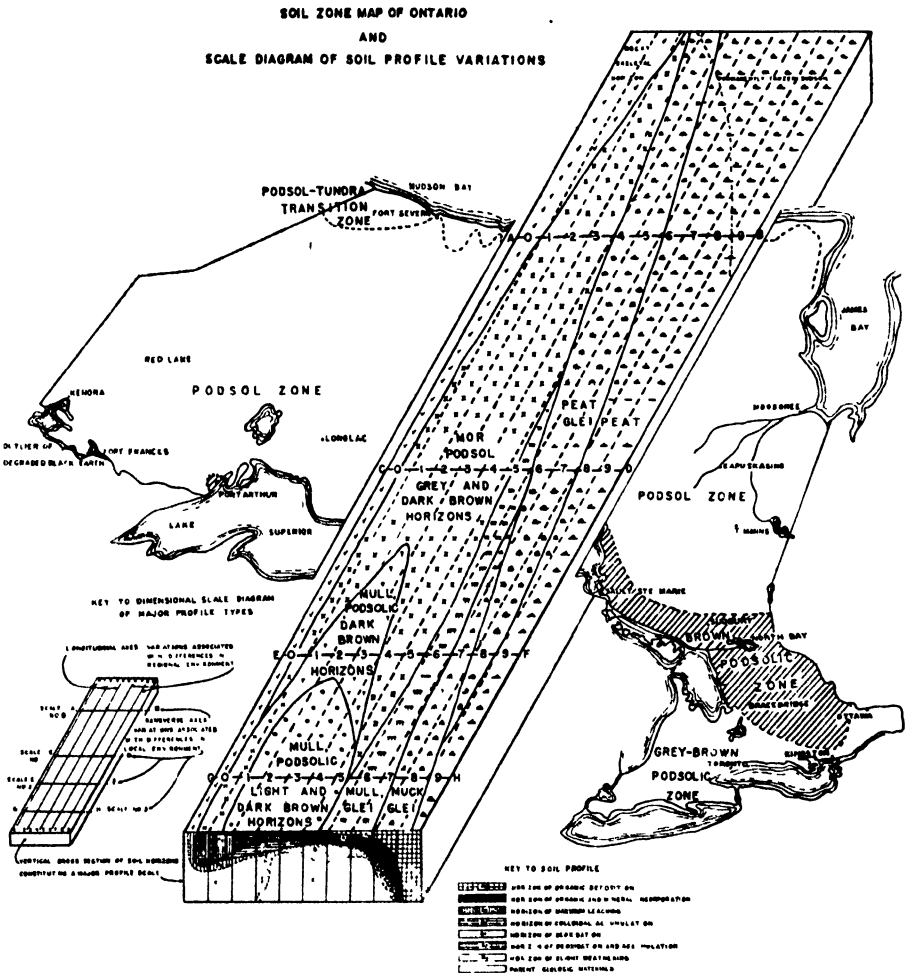


FIGURE 3. The scale diagram in Figure 3 is an attempt to show graphically the gradual slow changes throughout the province. On the longitudinal axes (with a north-south trend) are indicated the changes due to regional variations in climate. In Ontario is chiefly one of temperature. These regional changes give rise to soil zones. On the transverse axes are indicated soil changes due to local variations in climate. The east-west position of these axes have, therefore, no significance as to the east-west location of these local types. Cross sections along selected lines are shown in Figure 4.

gradually replaced by a horizon of accumulation in which much of the eluviated material remains in solution. Where the water table is more or less permanently high, a plastic subaqueous horizon, high in colloids, forms underneath the deep organic surface. A zone of alternate oxidation and reduction also becomes increasingly dominant until the position of a permanently high water table is reached. Rusty brown mottlings, which indicate alternate oxidation and reduction are found in both the horizons of eluviation and illuviation. The term glei has been applied to this zone of alternate oxidation and reduction and also to the greyish-blue, plastic, subaqueous horizon underlying the organic layer (see generalized diagrams, Figures 3 and 4). Factors which either singly or in combination tend to

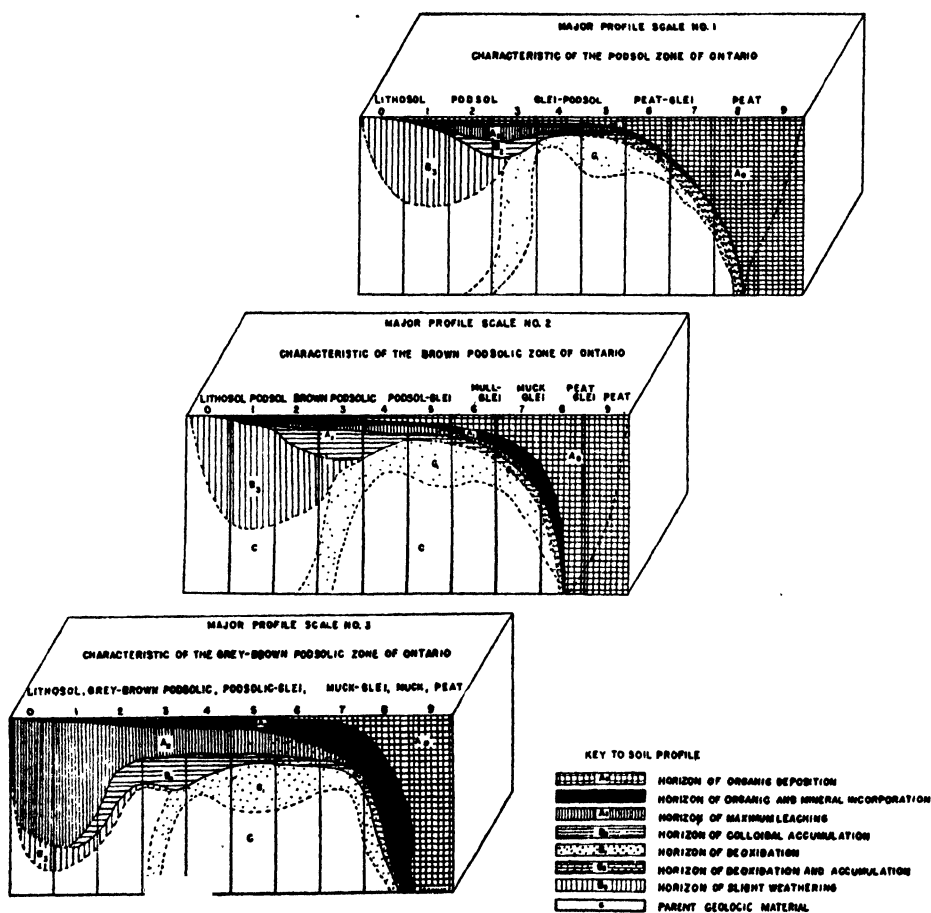


FIGURE 4. The Major Soil Profile Scales for Ontario.

increase the effectiveness of rainfall and render temperature less effective are: (1) heavy and compact soil materials, (2) smooth topography, (3) high regional water table, and (4) the initiation of a moor vegetation. True lithosols or hydrosols are barely within the pedologist's field and consequently are placed at the extremes of the scale and give little weight to the indices. Within the scale the change of characteristics from one

extreme to the other is gradual and varies considerably in detail in different soil materials. *While a separate scale diagram for each type of material within a climatic soil region may be considered desirable, a single combination scale has proven most useful providing its composite nature is recognized.*

Under the cool humid climate prevailing throughout Ontario, podsolization processes operate wherever drainage conditions permit. These are most active on the "normal" sites where the soil-forming factors permit the fullest expression of the climatic agencies. They become less active with the increased influence of those factors which tend to create the pseudo-arid or pseudo-maritime conditions. As drainage becomes poorer, podsolization is gradually replaced by gleization and increased organic accumulation. Figure 3 is a generalized diagram showing these types of profile development arranged according to the profile scale.

DISCUSSION OF CERTAIN PROFILES

Profile Index 0

The profile at index 0 may be described as an $A_0 - C_1$ type. This profile is developed under conditions which place the maximum restriction on the effectiveness of the rainfall.

The soil profile at this index is extremely shallow or may be entirely absent. The A_0 and A_1 horizons are very thin. The B horizon is also extremely shallow if present. The upper portions of the geologic materials are usually weathered slightly to form a C_1 horizon. Usually the site is excessively drained with the water table below 6 feet. The natural vegetation has modifications which adapt it for a dry environment, i.e. it is zerophytic.

Profile Index 1

The profile at index 1 may be described as an $A_{1-2} (B_2) B_3$ type. The factors which limit the maximum balanced development are the same as those outlined for index 0 but here they are operating with a lower intensity.

The A_0 and A_1 horizons are comparatively shallow. The A_2 is abnormal but variable, being very deep in siliceous materials and quite shallow if calcareous and argillaceous. The B_2 , if present, is very narrow. The B_3 horizon is usually quite thick in siliceous materials and very thin in those high in clay or lime.

Profile Index 2

The profile at index 2 may be described as an $A_{1,2,3} B_{1,2,3} C$. The environmental conditions are optimum for the maximum development of a well-balanced profile reflecting the regional climate and associated vegetation. The A and B horizons are well-developed and in proportion to each other. Both of these are well subdivided into subhorizons which reflect only those processes associated with the regional climate, which, in Ontario, are types of podsolization.

Soil drainage is good but not excessive. The water table is usually at depths greater than 6 feet. These features are usually conditioned by an undulating topography but are also found on smoother and more rolling sites depending on the texture of the soil material. Natural vegetation

may also play a dominant rôle in moisture control. The geologic materials are commonly of intermediate texture. Heavy soils with open structure and light soils with capacity to form moisture retaining horizons are also included. The petrographic nature of the parent material also affects optimum soil development. Very high content of either siliceous, argillaceous or calcareous materials will result in a development which is abnormal for the region particularly since the period of weathering in Ontario since glaciation has been so short. Conditions which are optimum for the maximum balanced soil development are likewise optimum for the development of the regional mesophytic vegetation, i.e., plants requiring normal moisture conditions. This is the climatic climax of the ecologist. (8).

Profile Index 3

The profile at index 3 is commonly marked by a slight under-development in both the A and B horizons and by the presence of slight mottlings. In the heavier soils the B horizon tends to be comparatively wide although there are indications that the material actually translocated is less densely accumulated at any particular point than is the case of the B at index 2. Factors which either singly or in combination tend to increase the effectiveness of rainfall and render temperature less effective are heavy and compact soil materials, gentle slopes and a higher regional water table.

Profile Index 4

At index 4 the effect of temperature is still further reduced by a coincidence of factors which retard soil drainage. Such factors have been outlined at Index 3 and include soil materials still heavier or more compact, a smoother topography, or a maintenance of the water table at a higher level than under the conditions prevailing at Index 3. The profile is commonly characterized by an induration of the B horizon. In the heavier soils there is a tendency to form the clay pan or otherwise cemented hardpan commonly associated with the planosols. (These hardpan conditions are not as highly developed in Ontario as in neighbouring areas of the United States which have been subjected to weathering for longer periods of time.) In the lighter soils, lenses of iron pan are found at this index. In nearly every case, there is a more pronounced mottling, indicating greater deoxidation.

Profile Indexes, 5, 6, 7, 8, 9

The development of these profiles is conditioned by a high water table which renders the leaching properties of soil water less effective. The result is a wider horizon of accumulation, a shallow grey leached horizon, and the maximum development of a deoxidized horizon (the glei). For variations see generalized diagram, Figure 4.

These are intrazonal hydromorphic soils which include the wiesenböden (of marshy meadows), the ground water podsols, and the half bog soils.

Profiles at indexes 8 and 9 indicate conditions where the influence of soil water is at its maximum and that of soil temperature is at its minimum. At index 8, the profile is that of a bog soil. The profiles of bog soils differ in detail with climate and adjacent upland areas. At index 9 are profiles transitional in nature between the bog soils and the true hydrosols.

FEATURES OF THE SOIL PROFILE REFLECTING REGIONAL CLIMATE

The features of the soil profile which reflect regional climate (found in the thousands column) are those associated with organic matter and soil weathering. Climate broadly determines the type of natural vegetation and accordingly the type of organic remains which is to be associated with the soil. Climate, too, is the factor which largely determines the extent to which organic matter will be incorporated into the soil and how much will remain on the surface. Climate determines the type of chemical weathering and the processes of translocation of the weathered products within the soil. The climatically controlled processes reflected in the soils of Ontario are organic accumulation, melanization, podsolization, and gleization.

Organic accumulation requires little definition. In cool, humid climates, the organic matter decomposes slowly and therefore accumulates on the surface in increasing amounts. A layer of slightly decomposed organic matter is termed the A_0 horizon. It is thin in places where the type of vegetation and the climate favours its decomposition and incorporation with the mineral soil. In this case, the decomposition may be proceeding rapidly to form a thick A_2 horizon. Where the process is slow, organic matter accumulates more rapidly and at greater depths. In profiles in which the organic matter of the A_0 tends to form an A_1 layer but slowly, the combined horizons are called *mor*, where the layer is shallow. Deeper layers of poorly decomposed organic matter are known as peat.

Melanization is the process of uniting organic and inorganic soil materials and results in the formation of a very dark horizon (the A_1). This is usually a mineral soil high in organic matter. It may also refer to a well decomposed and mineralized organic soil (muck). Melanization is associated with warm humid and subhumid climates. It is most highly developed under grass but may also be the dominant process under hardwoods. The process is promoted by a good calcium supply. In fact the northward extension of this process occurs mainly on sites on which the available calcium is high. Where the organic matter is being largely transformed from an A_0 to an A_1 condition, the combined organic horizons are often referred to as *mull*.

Podsolization is a leaching process which tends to remove iron and aluminum, etc., from the upper soil horizons and deposit them in a lower one. This leaching process occurs on the better drained soils of temperate forest regions, but becomes most intensive in the cooler and more humid regions of the coniferous forests with their unincorporated acid humus or *mor*. The downward-moving rain-water, percolating through the shallow layer of organic matter, becomes acid. These acidified waters remove varying amounts of iron, aluminum and other elements from the upper mineral layer depending on the type of organic matter through which it passes. The leaching results in an ashy grey horizon (A_2) low in iron and aluminum and rich in silica (sand). The degree of greyness in the leached horizon is usually indicative of the intensity of leaching. To these soils with an ash-like leached layer, the Russians have given the name "podsol". Underlying the leached A_2 horizon, the B, in which there is an accumulation of the iron, aluminum and clay colloids leached out of the A_2 above.

Gleization is the process involving the alternate oxidation and reduction of the products of weathering in a dispersed form. This process occurs under poor drainage conditions in all climatic regions. In warm regions it is associated with processes of humus incorporation. In the cooler, more humid climates, it is associated with the process of peat formation, in which there is organic accumulation with little melanization. Two phenomena result from the rise and fall of the water table. First there is the phenomenon of alternate oxidation and reduction. When the water table is low, the soil is aerated and oxidation takes place. When the soil is again saturated, the materials are reduced. The rusty, brown mottling which characterizes soils under these conditions indicate the presence of reduced iron oxides. This horizon is known as the glei (gley) or G_1 . Secondly, when the water table is low, the soil above it is subject to weathering and the products of weathering are leached downward. These accumulate in a dispersed form in contrast to the accumulation of precipitated colloids in the B horizon resulting from podsollic leaching. When in close proximity to the water table this horizon is commonly deoxidized and grey to blue in colour. In clay soils it is extremely plastic when wet, and brittle when dry. This horizon too, has been called the glei (gley), frequently the G_2 , to distinguish it from the G_1 , although often they occur in such intimate association that there is not a distinct line of demarcation between them.

All of these processes occur throughout Ontario, but there is considerable variation in the degree to which each is operating. The results are modifications in the major profile scale. If all the modifications within the province are to be taken into account, innumerable variations of the generalized scale would be necessary. However, the range of modifications has been divided into four, and scales have been established to represent four main climatic soil zones. Outliers of two other zones also occur. The subdivisions of the thousands column are indicated in Table 3. Further detail concerning regional types are illustrated in Figures 3 and 4.

TABLE 3.—THE KEY TO DIGITS IN THE THOUSANDS COLUMN

0. Tundra (Moor), Mean Line AB (Figures 3 and 4).
1. Podsol (Moor), Mean Line CD (Figures 3 and 4).
2. Brown Podsollic, Mean Line EF (Figures 3 and 4).
3. Grey Brown Podsollic, Mean Line GH (Figures 3 and 4).

CHOROLOGIC OR MAPPING UNITS

A chorologic or mapping scheme of classification is necessary since soils do not always occur in areas sufficiently uniform to use taxonomic units for mapping purposes. It has been conceived that a taxonomic type may embrace a reasonable range of characteristics. Upon this basis, Marbut established the soil type as a unit serving both taxonomic and chorologic purposes. The difficulties which have arisen through the failure to recognize the position of the soil type in the two classificatory systems are well-known to many soil surveyors. Kellog (5) points this out and stresses the need of the soil complex as a mapping unit of greater variability.

The chorologic or mapping unit, then, is a means of recording the distribution pattern of taxonomic units which the soil surveyor will encounter in the field. Certain taxonomic types must be considered as focal points from which to measure the degree of deviations. The soil surveyor first decides the taxonomic type and records it by means of the decimal symbol. If the characteristics in a mappable area are sufficiently uniform and do not extend beyond the range arbitrarily established for a taxonomic unit, it is evident that the area mapped will represent both a mapping and a taxonomic unit. When various decimal symbols appear on the field sheets in such a way that the separation of uniform areas of soil is impossible, a mapping unit covering a greater range of conditions is then established which may be more accurately called a soil complex. This unit embraces comparatively wide variations in type of geologic materials as well as change in the major profile class. If the unit mapped involves only profile variations upon similar parent material, the term catena (1) is used as indicated in Table 4. All soils in the same catena have the same tens and the hundreds column of the decimal symbol. The catena is similar to the soil association of Ellis (3). The terms series and types are common in the soil survey literature and should require no further discussion here.

TABLE 4.—SUMMARY TABLE SHOWING THE DECIMAL TAXONOMIC SUBDIVISIONS OF THE MAPPING SYMBOL

ZONAL TYPE	Catena		Series*	Type
	Geologic Fabric <i>Hundreds digit</i>	Petrographic Composition <i>Tens digit</i>		
<i>Thousands digit</i>				
0. Tundra	0 Thin drift	0. Almost equal proportions of argillaceous, siliceous and calcareous.	0. A ₀ -C ₁ profile	Textural Class <i>Tenths digit</i> s —sand ls —loamy sand sl —sandy loam fsl —fine sandy loam l —loam sl —silt loam scl —silty clay loam cl —clay loam c —clay h c —heavy clay
1. Podsol	1. Coarse textured till	1. Almost entirely argillaceous	1. A(B ₂)B ₁ profile	
2. Brown podsol	2. Loamy till	2. Mostly argillaceous, some siliceous.	2. A _{1,2,3} B _{1,2,3} C profile	
3. Grey-brown podsol	3. Heavy till	3. Mostly siliceous, some calcareous	3. A-B (G) profile	
	4. Roughly stratified gravelly drift	4. Almost entirely siliceous	4. ABG profile	
	5. Uniformly stratified gravelly drift	5. Mostly siliceous, some calcareous	5. A(B)G profile	
	6. Heavy deep-water sediments	6. Mostly calcareous, some siliceous	6. (M)AG profile†	
	7. Loamy deep-water sediments	7. Almost entirely calcareous	7. MG profile†	
	8. Roughly stratified sandy drift	8. Mostly calcareous, some argillaceous.	8. PG profile‡	
	9. Uniformly stratified sandy drift	9. mostly argillaceous, some calcareous	9. P profile‡	
	a. alluvial drift			
	l. loess			
	m. muck			
	p. peat			
	r. residual			

* 1 for grey-brown podsol zone.

† M (muck) melanized layer.

‡ 3 P for peat.

TABLE 5.—KEY TO MAJOR SOIL TYPES OF CARLETON COUNTY—A. Major Profile Types Common to the Grey Brown Podsollic Zone

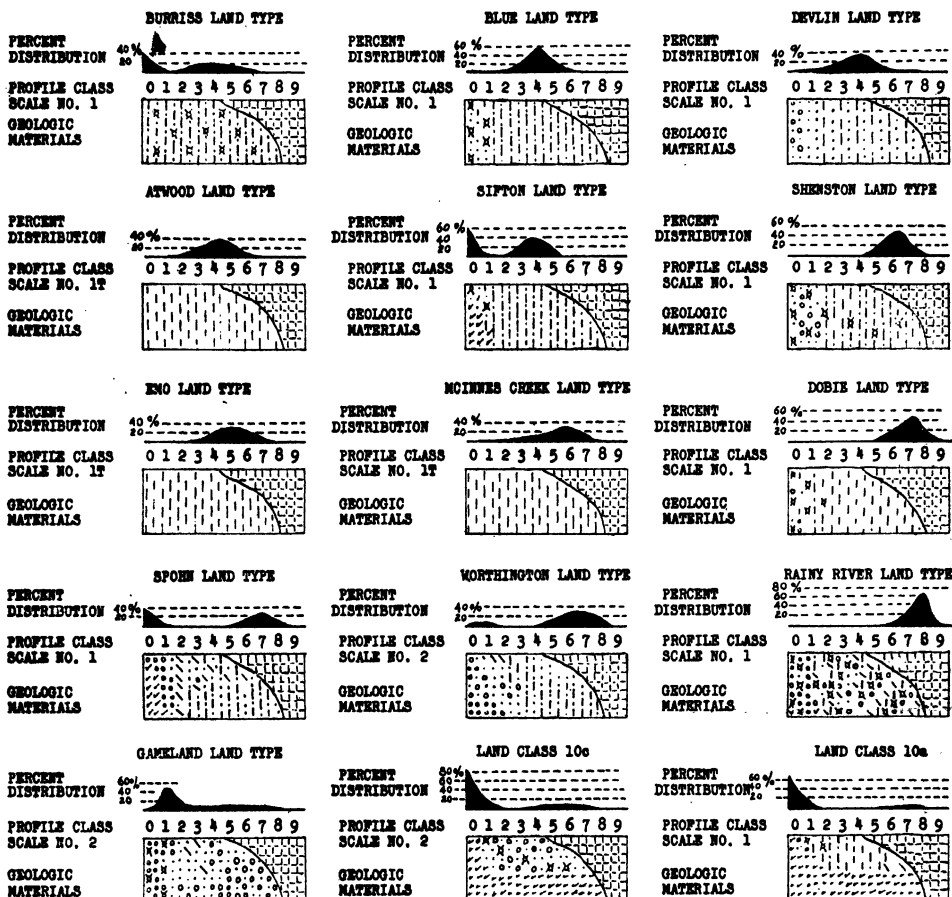
[illegible]

TABLE 5.—KEY TO THE MAJOR SOIL TYPES OF CARLETON COUNTY—Continued—B. Major Profile Types Common to the Brown Podsollic Zone

SCALE→	0	1	2	3	4	5	6	7	8	9
CHARACTERISTIC PROFILES FEATURES→	Thin grey brown surface horizon over slightly modified parent material. An A ₁ -C ₁ profile	Thin grey brown A ₁ weakly developed light grey A ₁ and brown B. An A ₁ -B ₁ (B ₁)-B ₁ profile	Grey brown surface, thin leached A ₁ and brown B. An A ₁ -B ₁ B ₁ -C ₁ profile	Grey brown surface thin leached A ₁ brown B and mottled G. An A ₁ -B ₁ -G profile	Dark grey organic A ₁ over leached A ₁ reddish brown B mottled glei. An A ₁ -B ₁ -G profile	Dark grey organic A ₁ over light grey leached A ₁ with mottling on lower part of profile the glei. An A ₁ -B ₁ -G profile	Dark grey A ₁ over greyish mottled A ₁ and glei. An A ₁ -B ₁ -G profile	Dark grey muck overlying mottled and/or sticky glei (G). An A ₁ -G profile	Brownish peat over dark mucky horizon then mottled or sticky glei. An A ₁ -G profile	Brownish peat. An A ₁ -G profile
ASSOCIATED CHARACTERISTICS→	Shallow steeply sloping or coarsely textured materials excessively drained	Rolling light textured land with excessive natural drainage	Rolling medium textured material not excessively drained under forest	Undulating land with natural drainage slightly restricted	Smooth land with moderate to slow natural drainage	Smooth land with slow natural drainage	Almost level land with very slow natural drainage	Almost level swampy land. Intermittent run-off. Internal drainage very slow	Depressional bog areas. Water held by ponding or by organic accumulations	Depressional bog areas. Water held by ponding or by organic accumulations
CATEGORIES↓	Loamy siliceous till, medium low in lime	Water laid grey clays and silts low in lime	Water laid pink and grey clays overlain by sands, clays and sands, low in lime	Water laid fine sands and silts, low in lime	Water laid sands over acid clays, low in lime	Uniformly stratified sands and gravels, low in lime	Shallow drift medium to low in lime over basic Precambrian bedrock	Shallow acid drift over acidic Precambrian bedrock	Wind blown sand	

The Soil Complexes, Types and Phases									
Galesburg sandy loam		Renfrew clay		Renfrew comp. subsoil		Bearbrook clay sand spot phase		Castor silt loam	
Manotick sandy loam		Allendale sandy loam		Rubicon sand					
Uplands sand		Chandos sand		Anstruther sand		Bridgman sand			
← Eastport sand →		← Eastport sand →		← Eastport sand →		← Eastport sand →		← Eastport sand →	

← ----- → indicates the profile range of at least 75% of the type as mapped.



NOTES:

- (1) **THE DISTRIBUTION GRAPH** in the upper part of each land type chart applies to the combination of the two groups of soil characteristics shown below it, namely; (a) The climatic soil profile types superimposed upon (b) The type of parent geological materials.
- (2) **MAJOR PROFILE SCALE NUMBERS** for numbers 1 and 2 see figures 3 and 4, also discussions accompanying these scales. No. 1T refers to a transition from podsol to the degraded black earths.
- (3) **PROFILE CLASS NUMBERS 0 to 9** indicate variations within major scales. See figure 4 and discussions under major profile classes.
- (4) **KEY TO GEOLOGICAL MATERIALS**

	ORGANIC MATERIALS		GRIT
	HEAVY TEXTURED LIMY MATERIALS		STONES
	INTERMEDIATE TEXTURED LIMY MATERIALS		PRECAMBRIAN BEDROCK
	COARSE GRAVELLY ACIDIC MATERIALS		

FIGURE 5. Distribution Pattern of Taxonomic Units.

While the use of the soil complex as a mapping unit expressing greater variability than the soil type is a step in the right direction, it would hardly seem to go far enough. To establish a boundary between these at any arbitrary point would merely indicate that the soil type is comparatively homogeneous and the complex comparatively heterogeneous. It would seem advisable to establish some device to indicate the distribution pattern of the taxonomic units. This the author has attempted to do in the following keys for Carleton County (10) and Rainy River District (11). (See Table 6 and Figure 5.)

An examination of Table 6 indicates that few of the soil types have a range as uniform as that of the taxonomic units with which they were measured. Many types such as the Grenville loam could be fairly easily identified by a single symbol, others such as the Lyons loam and Rubicon sand occupy portions of a catena. Then there are those such as Farmington clay which might run the whole gamut of the catena. The North Gower, as mapped, is neither a soil type nor a soil catena, but a soil complex since it is found on more than one type of parent material. In the reconnaissance survey in Northern Ontario (11) no attempt has been made to approximate homogeneity of the soil type. More inclusive and less precise mapping units namely the land class and the land type were established using land form and vegetation as the mapping criteria. While this demanded another mapping scheme than that used in the Soil Survey of Southern Ontario, it was found that the average range of profile characteristics could be described by using the same major profile scales. An attempt has been made to indicate the average distribution by a curve, (see Figure 5).

This system of classification was first used in Ontario during the Carleton County Survey in 1940. Since then it has undergone considerable changes and will doubtless require further modifications or clarification before it is suitable for all of Ontario. In spite of this lack of perfection, the system is now serving a very useful purpose not only in the correlation of soils within local areas, such as counties, but also in broader ecological studies of relationship of soils to crops and natural vegetation. Granted that its use demands considerable experience and knowledge of soils for those who would use it, it is doubtful whether a system of classification could be devised which would render soil survey a matter of simple routine.

ACKNOWLEDGMENT

The author is indebted to all those who were associated with him on soil survey projects sponsored by the Dominion and Provincial Departments of Agriculture. He is particularly grateful for the assistance of Messrs. N. R. Richards and L. R. Webber who laboured with him in the field and to Messrs. L. J. Chapman, A. Leahey, F. F. Morwick, D. F. Putnam and P. C. Stobbe for their liberality in constructive criticism.

Mr. R. N. Johnston, Chief, Research Division, Department of Lands and Forests, has kindly facilitated the final preparation of both manuscript and charts.

REFERENCES

1. BUSHNELL, T. M. Some aspects of the catena concept. *Proc. Soil Sci. Soc. Am.*, Vol. 7. 1942.
2. BUSHNELL, T. M. Taxonomic considerations in soil correlation. *Report of Soil Survey Assoc.* pp. 110-114. 1934.
3. ELLIS, J. H. A field classification of soils for use in the soil survey. *Sci. Agr.* 12 : 6. 1932.
4. JENNY, H. Factors of soil formation, McGraw-Hill Co., N.Y., pp. 70-75. 1941.
5. KELLOGG, C. E. Recent trends in soil classification. *Proc. Soil Sci. Soc. Am.* 3 : 253-259. 1938.
6. MERRILL, G. P. Rocks, rock and weathering and soils. Macmillan Co., New York, p. 44. 1897.
7. THWAITES, F. T. Outline of Glacial Geology. University of Wise. 1941.
8. WEAVER, J. E., and F. E. CLEMENTS. Plant Ecology, McGraw-Hill Company, N.Y. 1938.
9. WYATT, F. A., W. E. BOWER and W. ODYNSKY. Soil survey of Lethbridge and Pincher Creek Sheets. *Bull.* 52. University of Alberta. 1939.
10. HILLS, G. A., N. R. RICHARDS and F. F. MORWICK. Soil survey of Carleton County. Report No. 7, Ontario Soil Survey. 1944.
11. HILLS, G. A. and F. F. MORWICK. Soil Survey of Northwestern Ontario. In Press.

PHYSICAL FACTORS AFFECTING LAND USE IN A COMMON SOIL TYPE IN ONTARIO¹

N. R. RICHARDS²

Experimental Farms Service, Ottawa, Ontario

Farm lands in the Province of Ontario have a wide range of physical conditions that affect their use. These may be expressed on a detailed map by delineating areas showing soil type, degree of slope, and kind and degree of erosion. Present land use must be recognized since it may have a very decided effect on the extent to which a soil type suffers from the hazards of erosion.

A "Soil Type" (2) may be defined as a group of soils having genetic horizons similar as to differentiating characteristics, including texture and arrangement in the soil profile, and developed from a particular type of parent material. However any soil type is actually an expression of a range of conditions. A type characterized by level topography will not exhibit as many variations as one characterized by rolling topography. On the latter there is a wide range in degree of slope, drainage conditions, and the extent to which the type suffers from erosion hazards. A level soil type may be represented entirely in one slope class while one with rolling topography may be contained in several classes as is the case in the type under discussion. The smoother slopes, with good farming practices, can be cultivated without fear of excessive erosion. However, on the steeper slopes care must be exercised to protect the surface soil from eroding away since a definite relationship exists between degree of slope and soil losses. On a level soil type the drainage is usually relatively uniform throughout whereas on a rolling type it may vary from good drainage on the smooth slopes to excessive drainage on the steep slopes.

More than 75,000 acres of Bondhead fine sandy loam were recognized and mapped in Durham County and slightly more than 50,000 acres in Northumberland and York Counties. Formed from materials which are comprised largely of Trenton and Black River limestone the Bondhead fine sandy loam is commonly referred to as a till soil. The rolling topography provides adequate drainage over most of the type with the exception of the steep slopes which are often excessively drained. Stones are present throughout the soil profile, but not in sufficiently large numbers to interfere with cultivation. This soil exhibits a well developed profile common to the Grey Brown Podsollic soils and is described in Figure 1.

Mixed farming is the dominant type of agriculture being practised on the type. Small grains and hay are grown to feed live stock. Production of butterfat, beef cattle, swine and poultry form the basis from which the farm income is derived. Oats, wheat and barley are the most common grain crops grown.

Slightly over 4,000 acres of Bondhead fine sandy loam were examined in detail in a sample area of Hope Township, Durham County and an inventory made of the physical factors that affect the use of this soil type.

¹ Presented to the Soils Group of the Canadian Society of Technical Agriculturists at the Annual Convention, Toronto, Ontario, June 26-29, 1944.

² Agricultural Scientist, Experimental Farms Service, c/o Ontario Agricultural College, Guelph.

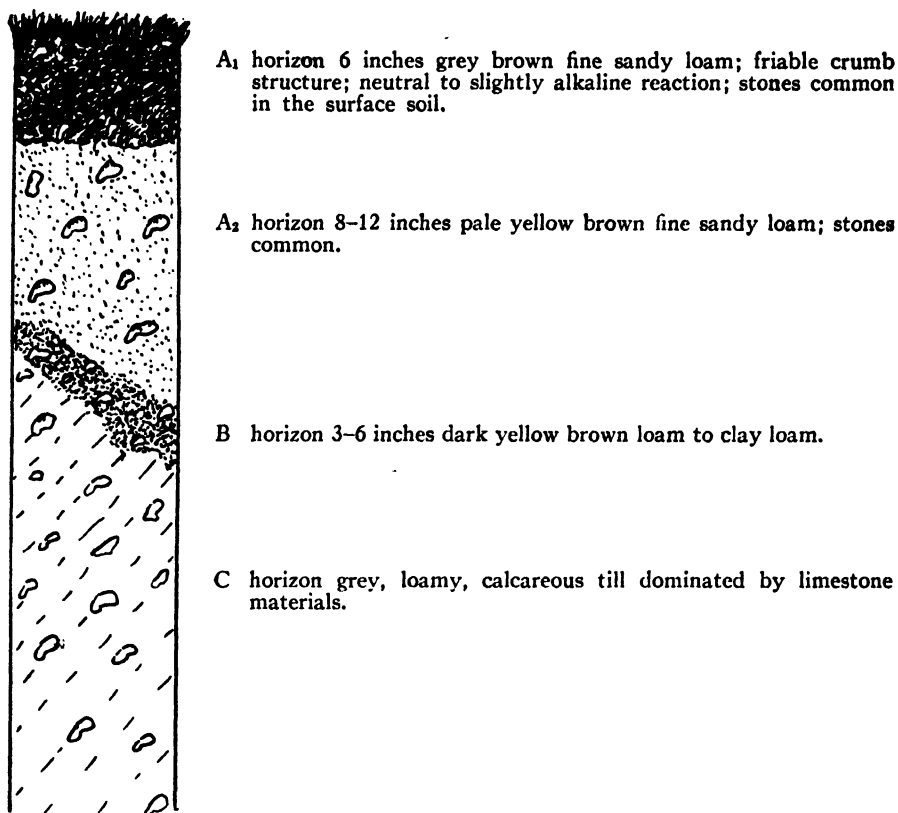


FIGURE 1. A cultivated profile of Bondhead fine sandy loam.

Present land use or cover was charted on aerial photographs. A series of vertical photographs taken in 1927 was obtained from the R.C.A.F. and formed a very useful and satisfactory base upon which to chart present cover. All lands planted to crops, fallow land, orchards and areas seeded down to crops grown in rotation were considered "*Cropland*". At the time of the survey 72% of the Bondhead fine sandy loam was contained in the Cropland class. Areas used for grazing and not in the regular system of crop rotation were mapped as "*Permanent Pasture*" and occupied 23% of the surveyed area. Much of the permanent pasture is located on the steep slopes as indicated in Figure 2 while the smooth slopes are cultivated. Land with 40% or more of its surface covered by trees was considered "*Woodland*". A little less than 4% of the Bondhead fine sandy loam in the surveyed area is under tree cover. The remaining 1% of the area was considered "*Idle Land*".

<i>Present Land Use</i>	<i>Percentage of area</i>
Cropland	72
Pasture Land	23
Woodland	4
Idle Land	1
Total	100

Slope affects the rate of run-off and consequently the susceptibility of a soil type to erosion. Slope was measured by use of the Abney Level, and six classes were established to express this factor.

TABLE 1.—SLOPE CLASS AND PERCENTAGE OF AREA OCCUPIED

Slope class	Area occupied
	%
A — 0-3%	1.8
B — 3-8%	43.5
C — 8-15%	43.2
D — 15-25%	6.8
E — 25-35%	2.8
F — 35% and over	1.9
Total	100.0

An experiment conducted at the La Crosse Experiment Station, La Crosse, Wisconsin (1) compares the soil losses from slopes of 3, 8, 13 and 18%. There are 3 plots on each slope, and the individual plots are 72 feet long up and down. Measurement of soil losses was made for two years with all twelve plots planted to barley. The average annual soil lost per year has been:

<i>Percentage slope</i>	<i>Average annual soil loss</i>
%	tons
3	0.69
8	2.34
13	6.80
18	17.19

It is interesting to note that the 18% slope is less than twice as steep as the 13% but the soil loss is almost three times as great. As the slope becomes increasingly steep the soil losses continue to increase even more rapidly. The erosion hazards are multiplied as the steeper slopes are cultivated.

Crops vary greatly in the amount of protection from erosion that they give to the fields on which they are growing. Permanent cover crops such as hay, pasture and woodland tend to hold the soil in place and reduce erosion because: (1) they cover the soil completely the year around, and (2) add to the organic matter and granulation of the soil thus increasing the water absorbing capacity which in turn decreases surface run-off. Cultivated crops, particularly row crops, usually increase soil erosion because they: (1) reduce soil granulation and the organic matter content of the soil thereby lowering the water-holding capacity and increasing the surface run-off; (2) do not occupy the soil throughout the year; and (3) do not cover the soil completely. Table 2 expresses the distribution of present land use according to slope group.

TABLE 2.—DISTRIBUTION OF PRESENT LAND USE ACCORDING TO SLOPE GROUP

Present land use	A slopes 0-3%	B slopes 3-8%	C slopes 8-15%	D Slopes 15-25%	E Slopes 25-35%	F Slopes 35% and over
	%	%	%	%	%	%
Cropland (2,892 acres)	2.1	48.0	43.9	3.8	1.9	.3
Pasture Land (932 acres)	1.7	35.6	40.8	11.6	3.4	6.9
Woodland (132 acres)	0	2.9	41.2	32.4	17.7	5.8
Idle Land (54 acres)	0	30.8	61.6	7.6	0	0

The figures in Table 2 indicate that almost half the area in cropland is located on slopes greater than 8%. Because of steep topography and susceptibility to erosion there has been a tendency to retire the areas having steep slopes to permanent cover of woodland or pasture.

The Bondhead fine sandy loam is susceptible to sheet erosion, and to express this factor five erosion classes were established.

<i>Erosion Class</i>	<i>Percentage of Area</i>
Little or no erosion	7.6
Slight erosion	43.6
Moderate erosion	38.8
Severe erosion	3.7
Very severe erosion	6.3
Total	100.0

TABLE 3.—DISTRIBUTION OF PRESENT LAND USE ACCORDING TO EROSION CLASSES

Present land use	Little or no erosion	Slight erosion	Moderate erosion	Severe erosion	Very severe erosion
	%	%	%	%	%
Cropland	5.9	43.4	44.1	2.7	4.1
Pasture land	13.3	45.5	26.2	5.2	9.8
Woodland	15.2	33.3	27.3	12.1	12.1
Idle Land	0	54.1	55.9	0	0

Because of its rolling topography and the extent to which it is cultivated the Bondhead fine sandy loam presents an acute erosion control problem. Special attention must be paid to the selection of suitable rotations, adapted farm crops, and to the application of erosion control practices if this soil type is to be successfully farmed. Pastures for the most part are located on land which was formerly used for crops. Erosion on pastures, therefore, is more severe than it would have been if the land had been maintained in grass. Some of the area mapped as woodland are plantings on severely eroded areas. Other wooded areas have been pastured and are showing signs of accelerated erosion. A large percentage of the idle land on the

Bondhead fine sandy loam will be cultivated again when sufficient labour and equipment are available. However over 55% of the area that is idle now will require intensive erosion control practices when cultivated.



FIGURE 2 Smooth slopes on the Bondhead fine sandy loam are cultivated, while the steeper slopes are used for pasture

After the four factors, soil type, present cover, degree of slope, and erosion have been measured they form the basis for planning improved land use on the surveyed area. Although each of the factors is significant in itself, it is desirable to group them into a simple classification that will express the capabilities of the land for use. Five categories were established on the basis of the physical characteristics which determine the capability of the land for use. Classes I, II, and III include land that is suitable for the regular use of growing crops that require tillage. Classes IV and V are not suitable for continuous cultivation and are best adapted for pasture or forest land.

Class I land can be cultivated safely and permanently without the use of special erosion control practices. Except for practices necessary to replace plant nutrients removed by crops, and the maintenance of good soil tilth, land in this class is capable of producing moderate to high yields of general farm crops. About 7.6% of the Bondhead fine sandy loam is contained in Class I.

Class II land can be cultivated safely provided fertility levels are maintained and protective measures such as the incorporation of legumes in the grass seed mixture and the maintenance of waterways in sod are employed to protect the soil from erosion. About 42% of the surveyed area is Class II land.

Class III land occupies 39% of the area. Land in this class is suitable for cultivation provided complex or intensive erosion control practices are employed. In this class, it may be necessary to use contour cultivation or strip cropping. Every effort must be made to conserve as much soil moisture as possible.

Because of steep slopes, irregular topography, or severe erosion, over 4% of the Bondhead fine sandy loam included in Class IV land would serve its greatest usefulness as Pasture Land.

Land Class V contains very severely eroded areas with rough, steep and broken topography. Even under grass cover, land in this class erodes readily. Forest cover is recommended for about 9% of the Bondhead fine sandy loam.

<i>Land Class</i>	<i>Percentage of Area</i>
I	7.6
II	41.8
III	37.2
IV	4.3
V	9.1
Total	100.0

Such an inventory of any soil type forms the basis for the development of improved land use. The results indicate that erosion control measures are urgently required if the land is to serve its greatest use capability. However, before recommendations are made, specific knowledge, field by field, must be obtained and the suggested protective measures must be fitted into an acceptable farm plan.

ACKNOWLEDGMENT

Much of the data presented in this article is taken from the report of the Soil Erosion and Land Use Survey of the Hope Township Project Area. Sincere thanks are due Professor F. F. Morwick who supervised the field work and the writing of the Hope Township Report.

REFERENCES

1. Cropping Systems that help control erosion. U.S.D.A. Bulletin 452.
2. Soils and Men. Yearbook of Agriculture, 1938. U.S.D.A.

CEREAL VARIETY ZONE CO-ORDINATION IN THE PRAIRIE PROVINCES

[Received for publication February 15, 1945]

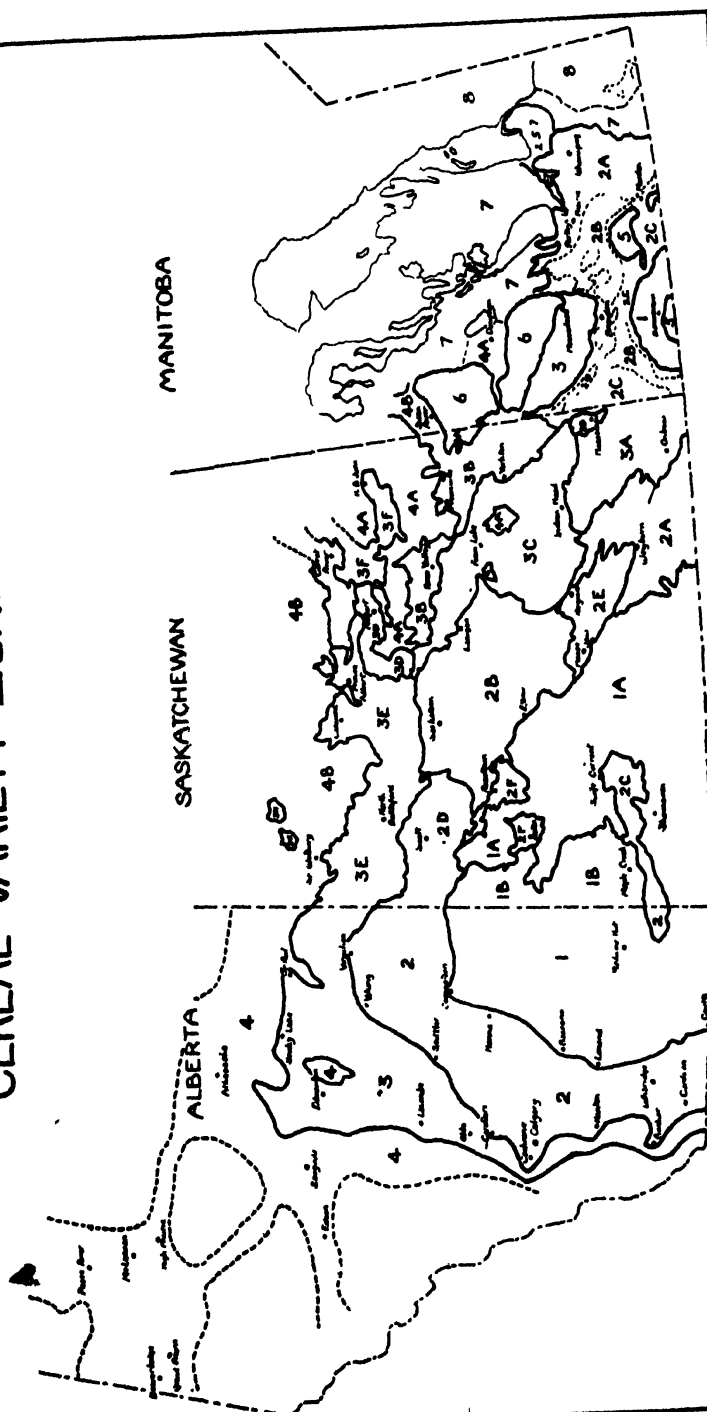
For the past 15 years the Cereal Variety Zone Co-ordination Committee of the Western Canadian Society of Agronomy has functioned to give coherence to the recommendations of the cereal committees of the three prairie provinces. The main purpose of the committee is to co-ordinate at the provincial boundaries the cereal zone boundaries and variety recommendations. The committee consists of six members, two being from each province as follows: Alberta, Dr. A. G. McCalla, University of Alberta, Edmonton, and Mr. W. D. Hay, Dominion Experimental Station, Lethbridge; Manitoba, Dr. C. H. Goulden, Dominion Laboratory of Cereal Breeding, Winnipeg, and Mr. W. J. Breakey, Dominion Experimental Farm, Morden; Saskatchewan, Mr. J. G. Davidson, Dominion Experimental Farm, Indian Head, and Dr. J. B. Harrington, University of Saskatchewan, Saskatoon (Chairman). Two of the previous reports of this committee have been published in *Scientific Agriculture*, namely, in 1933 in vol. 13, pp. 473-475, and in 1936 in vol. 17, pp. 259-263.

The co-ordinating committee, at its last annual meeting, which was in June, 1944, at Saskatoon, adopted the plan of preparing for publication a brief annual report accompanied by an up-to-date cereal zone map of the prairie provinces. It was considered that there was, among the technical agriculturists of Canada, sufficient general interest in cereal zonation to warrant the publication in January or February each year of a co-ordinated picture of the current cereal variety recommendations for the prairie provinces.

In order to have more effective co-ordination of the zones and recommendations which are drawn up and approved by the cerealists of the prairie provinces, the three cereal committees, at the suggestion of the co-ordination committee, have staggered the dates of their meetings and arranged for a representative to attend the meeting of the cerealists of the adjacent province where possible. For example, the Alberta Varietal Zonation Committee, and the Manitoba Agronomists, which includes the Manitoba Cerealists, held their 1944 annual meetings the middle of December, one week before the Saskatchewan Cereal Variety Committee had its meeting. The interchange of representatives at the meetings of the cerealists, although not yet consummated as completely as is desirable, has already been most valuable in the promotion of co-ordination.

Staggering the dates of the meetings and exchanging delegates would not of itself effect co-ordination. The Alberta and Manitoba committees are well aware of the desirability of making no zone boundary change or recommendation that would upset the status quo without first taking up the point with the Saskatchewan Cereal Variety Committee and trying to come to a decision that would be satisfactory to the provinces concerned. Similarly the Saskatchewan cerealists, because their province is adjacent to each of the other provinces, realize the need for synchronizing Saskatchewan zone boundary changes and recommendations with those of Manitoba and Alberta.

CEREAL VARIETY ZONES 1944



ZONES

The cereal variety zones of the prairie provinces follow the soil zones very closely and in Alberta and Manitoba are almost synonymous with the soil zones. These zones are designated by arabic numerals with, in most cases, sub-divisions indicated by letters. The sub-divisions are to accommodate cereal variety recommendations where climatic differences, important to cereal variety growth and ripening, occur. The principal characteristics of the basic soil zones furnish a rough background for varietal recommendations. In Alberta and Saskatchewan the shallow brown soils subject to frequent drought constitute Soil Zone 1. Zone 2 comprises the dark brown soils and in Alberta the shallow black soils, and is less subject to drought. Zone 3 includes the black, deep black and degraded black soils and has much better moisture conditions than Zone 2. Grey and strongly degraded black soils and a relatively short frost-free season characterize Zone 4. In Manitoba Zone 1 is transitional like Zone 2 of the other provinces, Zones 2, 3 and 4 are different types of black soil, Zones 5 and 6 are somewhat comparable to Saskatchewan Zone 4, and Zone 7 comprises wooded areas with soil of high lime content.

VARIETY RECOMMENDATIONS

FACTORS CONSIDERED

There are a number of basic considerations which determine the recommendations of varieties. Some of the more significant factors are the following:

Yield is the most important and itself depends on various inherited and environmental factors. A variety may yield better in Manitoba or Alberta than in Saskatchewan, or vice versa, and it is recommended accordingly. Regardless of its potential yield a variety may not be recommended for a given area if its susceptibility to disease, or weather conditions, etc., makes its use there hazardous.

Length of growing season of a variety is very important where it is likely to exceed the normal frost-free period. For example, only early varieties of wheat and flax would be recommended in the northern parts of Alberta and Saskatchewan. On the other hand, oats with a short growing period do better than late oats in the southern areas of Saskatchewan and Manitoba.

Strength of straw is of chief significance in the moister areas where yields are high, but it is of general importance throughout the West; even in the dry areas occasional crops grow tall and rank.

Reactions to specific diseases are important according to the likelihood of epidemics. For example, stem rust of wheat may cause serious loss in Manitoba and Saskatchewan but the danger is slight in western Saskatchewan and Alberta. To a certain extent the same is true of rust in barley, oats and flax.

Length of straw, bushel weight and resistance to shattering and after harvest sprouting all may be deciding factors under certain conditions.

WHEAT

Thatcher is recommended throughout the prairie provinces which shows that this variety suits widely varying conditions. Regent is not recommended in Alberta nor is it recommended in any adjacent zone of Saskatchewan excepting 3E and in that case it is only considered well suited to the eastern part of the zone. Regent is recommended in all adjoining zones of Manitoba and Saskatchewan. Renown is recommended in Manitoba Zones 3, 4B and 6 but not in Saskatchewan. This is not inconsistent as Renown has yielded comparatively better in Manitoba than in Saskatchewan.

Reliance is recommended for Zone 1B of Saskatchewan and Canus for Zones 1 and 2 of Alberta. These are high yielding sister varieties of similar performance and both are susceptible to rust, which is much more important in Saskatchewan than in Alberta and accounts for the restricted recommendation of Reliance, compared with that of Canus. Somewhat similarly, Marquis and Red Bobs, both susceptible to rust, are recommended in Alberta but not in Saskatchewan excepting for the small northwestern zone 3H. Rust-susceptible varieties are discarded earliest where the rust threat is greatest. Thus no rust-susceptible variety of wheat is recommended in Manitoba, only two are recommended in Saskatchewan and they are restricted to the extreme west, and in Alberta no variety has been discarded because of susceptibility to rust.

As for *durum* wheat, Mindum is recommended for Zones 1 and 2 in Manitoba and for eastern Saskatchewan; Pelissier, which is more drought resistant than Mindum, is recommended for central and western Saskatchewan while in Alberta no durum is recommended. These recommendations are to be expected since the principal reason for using durum varieties in Western Canada has been their resistance to rust.

OATS

Oat recommendations also make a coherent picture, stress being laid on rust resistance in Manitoba, drought resistance plus rust resistance in Saskatchewan, and yield and straw strength in Alberta. In Manitoba, Ajax and Vanguard are recommended in all zones and Exeter in Zones 3 and 7. In Saskatchewan, Vanguard is no longer recommended, it being replaced by Ajax and Exeter which outyield Vanguard under the drier conditions of that province. Banner and Victory, although susceptible to rust, are still recommended in many zones but none of these adjoins the agricultural areas of Manitoba. These varieties are much alike and the recommendation of Banner in Zones 1A, 1B and 2D of Saskatchewan and Victory in the adjacent zones of Alberta, Zones 1 and 2, is probably largely a matter of local preference and does not signify an important divergence in viewpoint. Neither Ajax nor Exeter are recommended in Alberta because rust has not been a factor in oat production and because the older varieties Legacy and Eagle have done well in Alberta as early and late varieties, respectively.

BARLEY

In discussing barley recommendations two things should be kept in mind. These are (1) the need for drought resistant varieties on the open plains of Saskatchewan and Alberta, and (2) that Newal does best toward the West and North whereas Wisconsin 38 and Plush do best in the East. In Manitoba, Plush, Wisconsin 38, Sanalta and Rex are recommended as feed barleys in all zones. For the adjacent zones of Saskatchewan, Plush and Rex are recommended but not Wisconsin 38 or Sanalta. In Alberta, Newal, Trebi and Sanalta are recommended for Zones 1 and 2; these varieties plus Olli are named for the irrigated areas. In Zone 2, Newal and Olli (North only) are recommended and the same varieties are recommended in Zones 3 and 4. In Saskatchewan, Prospect and Rex are recommended for Zone 1, and Newal, Plush and Regal along with Rex in the Zones 2D, 3E and 4B which are adjacent to Alberta. In Alberta the performance of Newal has been so satisfactory that it is the only smooth-awned variety recommended. It would seem that greater co-ordination of feed barley recommendations at the Alberta-Saskatchewan boundary should be sought. However, the present apparent lack of co-ordination is not serious considering that conditions in eastern Alberta are not identical with those of western Saskatchewan.

For malting barley O.A.C. 21 is recommended in all zones of Alberta, the northeastern and eastern zones of Saskatchewan, and all of the Manitoba zones excepting the southwestern region. In addition Olli is recommended for Zones 3 and 4 of Alberta, and Mensury is an alternative to O.A.C. 21 in Manitoba. The principal lack of co-ordination here is the recommendation of O.A.C. 21 for the open plains zones of Alberta but not of Saskatchewan. However, it is recognized by the cereal committees of these provinces that the growing of malting barley should not, as a rule, be attempted on the dry open plains. Mensury is very similar to O.A.C. 21 and was omitted from recognition by the Saskatchewan cerealists on that account. Thus there is excellent agreement between Manitoba and Saskatchewan as to malting barley recommendations. The recommendation of Olli in Alberta is in accord with its favourable mention for north-eastern Saskatchewan.

FLAX

The flax recommendations show satisfactory co-ordination in that Royal is recommended for all central and southern areas, and Redwing for the northern and other shorter season areas. In Manitoba, Buda does well in some areas and is an alternative to Royal whereas, in Alberta, Bison is recommended along with Royal in Zones 1 and 2. The rust and frost susceptibility of Bison have not been as important factors in Alberta as in Saskatchewan.

CONCLUSION

On the whole there is reasonably satisfactory co-ordination of cereal zones and variety recommendations in the prairie provinces. Undoubtedly the use of a uniform soil classification throughout the Prairie Provinces

would be helpful in bringing about a full co-ordination of cereal variety zones. It is hoped that this materializes within the next few years. A certain amount of discrepancy may continue in the variety recommendations, but this may be more apparent than real. Each committee of cerealists endeavours to keep the number of recommended varieties at a minimum. Thus when one province recommends a given variety A it is less likely to advocate another variety B which is somewhat similar to A but does not excel it. If, then, the adjacent province happened to recommend B first it would similarly not recommend A. Here would be a case where the actual difference in recommendation is slight yet appears to be large. The existing variety recommendations of the Prairie Provinces show more fundamental consistency than is apparent and in general it can be concluded that a fair degree of co-ordination has been achieved.

J. B. HARRINGTON, *Chairman*

February 15, 1945.

EPIDEMIOLOGY OF STEM RUST IN WESTERN CANADA¹J. H. CRAIGIE²*Dominion Laboratory of Plant Pathology, Winnipeg, Manitoba*

[Received for publication March 27, 1943]

INTRODUCTION

Recurrent outbreaks of stem rust (*Puccinia graminis* Pers.) have been responsible during the present century for a great deal of damage to cereal crops in Western Canada, particularly to wheat. Although severe epidemics have occurred only periodically, yet the disease has been present every year and has caused a greater or less amount of damage. As a matter of fact, as early as the year 1896, it caused considerable damage in Manitoba (16). A heavy outbreak occurred in 1904, but it was not until 1916 that the loss caused by it reached calamitous proportions. In that year, the loss in wheat amounted to 100,000,000 bushels (29, 65, 189). Since then several other very destructive outbreaks have occurred, notably in 1923, 1927, 1935, and 1938. Calculations made recently (79) show that, for Manitoba and Saskatchewan, the average annual loss in wheat between 1925 and 1935 was in the vicinity of 35,518,000 bushels, and, in oats, for the 6-year period 1929-1934, around 8,334,000 bushels. For Manitoba, the yearly loss in barley between 1916 and 1937 was estimated at 2,350,000 bushels (44). Rye has never been injured to any appreciable extent. Within the last few years, losses from stem rust have been largely eliminated in wheat and oats by the extensive introduction of rust-resistant varieties of these two cereals.

As is well known, Western Canada is largely a cereal-producing area. Wheat is the most important crop, occupying a total of approximately 23,200,000 acres, 2,500,000 being in Manitoba, 13,200,000 in Saskatchewan, and 7,500,000 in Alberta. Approximately 9,500,000 acres are sown to oats, about one-half being in Saskatchewan, one-third in Alberta, and the remainder in Manitoba. Barley occupies a little in excess of 3,000,000 acres, about equally divided among the three provinces. Only about 700,000 acres are sown to rye, distributed among the three provinces in about the same proportion as given for oats.

Seeding and harvesting of wheat usually become general a week or more earlier in the southern than in the more northerly parts of the three provinces. The actual dates for seeding and harvesting vary a good deal with the season. Perhaps the last week in April and the second week in August may be taken as the usual time, respectively, when seeding and

¹ Contribution No. 804 Botany and Plant Pathology, Science Service, Department of Agriculture, Ottawa, Canada.

² Officer in Charge.

from east to west. Manitoba has suffered most from these attacks, Alberta the least; although not infrequently in Alberta late crops have been heavily rusted.

Three different varieties of stem rust occur on cereal crops in Western Canada. The variety that attacks wheat and barley (*Puccinia graminis Tritici* Erikss. & Henn.) is the most important. Barley, however, has never suffered so severely as wheat, for the bulk of this crop ripens earlier than the wheat and, on this account, has usually escaped the full force of severe outbreaks, although, in bad rust years, late barley has always been severely damaged. Next in importance comes stem rust of oats (*Puccinia graminis Avenae* Erikss. & Henn.). It has usually been severe in years when stem rust has been heavy on wheat, although this has not always been the case. For example, in 1937, infection on wheat was severe in south-central and central Manitoba and moderately severe in the eastern portion, but infection on oats was of no consequence. On the other hand, in 1932 and 1934, two non-epidemic years, oat stem rust was more prevalent than wheat stem rust. The third variety, stem rust of rye (*Puccinia graminis Secalis* Erikss. & Henn.), has never been of any importance. As a rule, little more than a trace of this rust has ever been found on the rye crop.

PURPOSE AND PLAN OF THE INVESTIGATION

As already stated, stem rust has been present every year in Western Canada since the beginning of the present century, but it has been more destructive in some years than in others. An investigation, extending over a period of years, has been made (a) to determine the source of the inoculum that yearly initiates stem rust in this area, (b) to detect each year the first appearance of the disease in the field, (c) to observe its subsequent rate of development and direction of spread, and (d) to ascertain if possible what factors promote or retard the intensity of its attack.

Some phases of the investigation were begun in 1918, but the bulk of the data presented in this paper has been accumulated since 1925. At the beginning of the investigation, relatively little was definitely known concerning the source of inoculum that initiated outbreaks of stem rust in this region, although three possible sources were recognized: (a) aeciospores from the common barberry, (b) uredial material that overwintered, and (c) wind-borne spores that originated in some other area. These three possibilities were studied with the view of determining to what extent each might be a contributory factor toward the establishment of primary infections in the new crop. In addition, field surveys were carried out each year to observe the progress of the disease and to determine the area affected by it. And, finally, meteorological data were studied to ascertain the influence of different meteorological factors on the development and spread of the disease.

Owing to the fact that spring wheat is the most important crop in Western Canada and the one most frequently and severely affected by stem rust, it was in this crop that the best sequence of observations were possible on the development and spread of the disease, and, consequently, the discussion in this paper deals principally with wheat stem rust (*Puccinia graminis Tritici*) in spring-sown wheat. As, in 1939 and subsequent years,

the area seriously affected by stem rust has been sown to stem-rust resistant varieties of wheat and oats, the data considered in this paper terminate with the year 1938.

SEQUENCE IN TIME AND PLACE OF EARLY INFECTIONS

It will make possible a better understanding of the other aspects of the study if a general statement is first made as to the sequence in time of the first appearance of stem rust in different parts of Western Canada. The field surveys have shown that, year after year, outbreaks of stem rust follow the same general course of development, although the severity of the outbreaks may vary very markedly. Initial primary infections never become common in a district until after the crop, or a considerable part of it, in that district has headed or is coming into head. Almost without exception, the first traces of the disease occur in southern Manitoba, more often than not in the Red River Valley. About a week after the first traces appear, widely scattered pustules are usually found over most of the southern part of this province. Occasionally, however, as in 1929 and 1935, a uniform sprinkling of pustules may appear almost simultaneously over this whole area. In either case, the time of appearance is usually the last week of June or the first week in July. Further north, the disease makes its appearance somewhat later. For instance, in the Swan River Valley, the most northerly agricultural area in Manitoba, the advent of stem rust is usually from two to three weeks later than in the Red River Valley. In Saskatchewan, stem rust appears first, as a rule, in the south-eastern part, and from a few days to two weeks, or more, later than in southern Manitoba. Northward and westward, there is a progressive delay in the date on which stem rust first appears in the crop. As might therefore be expected, the disease usually reaches Alberta later than it does western Saskatchewan, and a month or more later than it does southern Manitoba. Table 1 gives the dates on which stem rust was first detected each year in the field in the three Prairie Provinces from 1926 to 1938.

TABLE 1.—DATES ON WHICH STEM RUST OF WHEAT WAS FIRST DETECTED IN THE FIELD IN THE THREE PRAIRIE PROVINCES, FROM 1926 TO 1938

Year	Manitoba	Saskatchewan	Alberta
1926	June 30	July 14	Aug. 17
1927	July 6	July 17	Aug. 15
1928	July 9	July 20	Aug. 21
1929	July 3	July 5	Aug. 23
1930	June 26	July 11	Aug. 10
1931	July 5	July 25	Sept. 5
1932	June 20	July 22	Aug. 12
1933	June 28	July 14	Sept. 8
1934	July 5	July 16	Aug. 4
1935	July 2	July 7	Aug. 15
1936	June 26	July 3	Aug. 6
1937	June 28	June 28	Sept. 3
1938	June 22	June 21	July 29

POSSIBLE SOURCES OF INFECTION**INFECTED BARBERRY AS A SOURCE OF INFECTION**

The common barberry (*Berberis vulgaris* L.) is the alternate, or secondary, host of stem rust (Figure 2). It is generally regarded as the principal source of the disease in areas where the winters are too severe to permit the survival of the uredial stage of the organism from one crop



FIGURE 2. Common barberry bush, the alternate host of the stem-rust fungus. (Courtesy of the United States Department of Agriculture).

season to the next, although wind-borne spores may be responsible in greater or less part for the initial infections in such areas and overwintering may occur in a few of them. Most of these areas lie in the north temperate zone, and include all or practically all European countries (5, 6, 12, 18, 27, 60, 77, 80, 87, 90, 100, 109, 116, 120, 121, 126, 145, 177, 178, 181, 182, 185,

190, and others), at least some parts of Eastern Asia (86, 173, 183), the northern United States (23, 57, 108, 113, 141, 144, 149, 165, 176, 189, 191, 205, 206, and others), and Canada (41, 95, 99, 146). In many of these areas, the eradication of barberry has greatly lessened the amount of infection from this source (27, 61, 80, 85, 88, 90, 119, 157, 190, 195, 211) and apparently in a few others barberry has never become established (68, 183). In warmer areas, barberry rarely becomes infected or is largely absent, and is consequently of little or no importance in the perpetuation of the disease from year to year (1, 30, 48, 72, 112, 113, 127, 131, 134, 138, 160, 161, 163, 206, 223, 229, 230). Where barberry is present in such areas, infection is largely or entirely prevented, apparently because the black spores are devitalized by the excessive heat of summer (31, 94, 113, 193, 206). In Argentina, barberry species may be of some importance as a source of infection (175), but to what extent they play a part in the origin and yearly survival of races of stem rust is not known (221).

In Western Canada, the common barberry was never extensively introduced. It was planted as an ornamental shrub in some of the cities and a few towns, but, in the country, the number of plantings was very limited. Following the epidemic of stem rust in 1916, the three Prairie Provinces, particularly Manitoba, commenced (1917) the eradication of this shrub, and most of the plantings were destroyed within the next few years. An Act passed by the Dominion Government in 1919 forbade the distribution and sale of barberry plants in these provinces, and authorized the eradication of all plantings. By 1925 the eradication was virtually completed (99), and since that time no new plantings have been discovered. Nevertheless, since that time three extremely destructive outbreaks of stem rust have occurred (1927, 1935, and 1938) and three of moderate severity (1925, 1930, and 1937). It would appear, therefore, that local barberry plantings were not a principal source of infection in Western Canada. In passing, it should be mentioned that, although the number of barberries in this area were few in comparison with the number in some other areas, those that were present did serve as distribution centers of early inoculum, and their eradication has, therefore, removed from the localities in which they were present a perennial source of infection.

OVERWINTERED RUST AS A SOURCE OF INFECTION

It is now quite well established that the stem-rust organism, in the absence or non-participation of its alternate host, the common barberry, is capable of surviving in the uredial (red) stage from year to year in certain parts of the world where climative conditions make the persistence of this stage possible. In other words, the red stage of the rust is said to overwinter (or "over-summer" in certain areas). This stage is known to persist throughout the year in Australia (40, 127, 128, 229, 230, 232), New Zealand (43), Kenya (30, 114, 217), Tunis (37, 160, 161), Italy (42, 184, 186), possibly in Portugal (19, 20) and Japan (86), in sub-tropical South America (72, 73, 74, 223), and in some districts in the Foothills of northern India (131, 132, 134, 135). In North America, it overwinters in some of the milder parts of the United States (85, 113, 189, 192, 193, 195), including the Pacific coastal region, some protected mountain valleys, and the Gulf States, and in southern and probably in northern Mexico (213).

But in other parts of the world where the winters are moderate to severe, this stage does not overwinter, or, at least, it overwinters to such a limited extent that its survival is a negligible factor in the annual recurrence of the disease. This is true of most countries of Europe (8, 55, 56, 59, 68, 75, 100, 109, 111, 126, 130, 133, 145, 172, 177, 178, 182), the Amur Region in Eastern Asia (173, 183), the northern half of the United States (33, 39, 91, 102, 153, 156, 157, 158, 165, 176, 189, 190, 193) and probably Eastern Canada. In the latter area, Fraser (64) found that a very low percentage of urediospores survived the winter in Quebec, but the possibility of stem rust overwintering has not been adequately investigated. In passing, it may be mentioned that, in certain areas, such as the Plains of India (31, 131, 132, 134, 135), the persistence of the uredial stage is prevented, not by winter conditions but by the intense heat of summer.

There are three possible ways in which the uredial stage of the stem-rust fungus may persist during the period between one crop season and the following one. It may persist (a) by successive infections, each new generation of spores giving rise to new infections, (b) by dormant mycelium in infected host tissue, or (c) by long-lived urediospores. The first possibility presupposes the presence of green susceptible plants and weather conditions suitable for infection. As, in Western Canada, the period between crop seasons includes five winter months during which all plant growth out-of-doors is suspended, there is no possibility of the fungus persisting, or overwintering, by means of successive infections. If, therefore, the fungus persists, or overwinters, at all, either the mycelium in infected plant tissue must be dormant throughout the winter and revive sufficiently in the spring to produce a new generation of spores, or urediospores produced in the previous season must remain alive through the winter and early spring until new growth of susceptible grass or grain is available for them to infect. Unless the fungus can establish new infections in the spring or early summer by one of these means, it cannot be said to overwinter.

Possibility of Overwintering by Means of Dormant Mycelium

The possibility of the uredial stage of stem rust persisting as dormant mycelium in host tissue throughout the winter in Western Canada is undoubtedly remote. In order that the fungus may survive as dormant mycelium, the host tissue that it pervades must itself remain alive, for, if the tissue were to die, the mycelium would be deprived of its source of nutrient supply and would die of starvation even though it did succeed in surviving the winter in a dormant condition. It would not, therefore, be able to develop and produce urediospores in the spring. It is by these spores alone that infection could spread from overwintered mycelium. Actually, at the beginning of winter, there is relatively little living plant tissue in which the fungus can have any chance of survival. All cereal crops are harvested in late summer or early autumn, and the stubble soon afterwards dies. No winter cereals are grown, except a relatively small acreage of winter rye in the three provinces, and a little winter wheat in southern Alberta. Frosts in late autumn and early winter kill practically all the native grass vegetation down to ground level before a covering of snow arrives to afford it protection. Only in an occasional sheltered

location do the basal leaves of any susceptible grass, such as wild barley (*Hordeum jubatum* L.), enter the winter in a living condition. The grass culms usually ripen and die long before winter sets in. Severe winter weather usually prevails from mid-November to early April, during which time the ground is continuously frozen and is usually covered with a light to moderate blanket of snow. During this period, all plant growth out-of-doors is suspended. No new grass vegetation appears until about the beginning of May, and, by the end of May, the spring-sown grain is little more than above ground.

Conditions between crop seasons are, therefore, wholly adverse to the survival of the rust during that period. As a rule, the earliest infections to appear in the new crop occur on wheat. If overwintering were to occur in winter rye, it would be expected that the first infections would appear on that crop or on nearby couch grass (*Agropyron repens* L.), a grass susceptible to rye stem rust. But this is not known to occur. Even if the mycelium were to persist in rye, infection could not spread from rye to wheat, as rye stem rust does not infect wheat. Overwintered mycelium in winter wheat in southern Alberta cannot be the source of early infection, as stem rust never appears there until late in the season, a month or more after it is present in the Red River Valley in Manitoba, 600 or 700 hundred miles distant.

Possibility of Overwintering by Means of Urediospores

How long urediospores can remain viable appears to depend a good deal on the conditions to which they are subjected after they are produced. DeBary (51) found that urediospores, when stored in the laboratory, lost their ability to germinate within 2 months. Schaffnit (180) obtained similar results with spores stored in the laboratory or out-of-doors in a sheltered location. In tests made by Jaczewski (100), spores collected on July 25 ceased to germinate 14 days later. When fresh spores, obtained artificially in October and November, were exposed to outside temperatures, germination ceased within 6 days. Sibia (184) failed to obtain germination in urediospores after they were in storage for 20 or 22 days. From extensive tests, Hwang (97) came to the conclusion that the majority of urediospores in the air lose their vitality in from 12 to 14 days. Mehta (13) kept urediospores, which were produced in the greenhouse, in cold storage at a temperature of from 11.7° to 18° F. below the freezing point and found that, after 24 hours, less than 10% of them were capable of germination, and that after from 4 to 7 days none of them was germinable. Eriksson and Henning (59) found that urediospores stored in the open air during winter soon lose their power to germinate, but that unurediospores on straw stored in a room or laboratory, and thus protected from the vicissitudes of the weather, may retain their viability throughout the winter, a low percentage of such spores being capable of germination as late as May in the following spring. Pritchard (165) made various dispositions, both in the open and under cover, of sheaves of rusted straw that had stood in stook in the field until late autumn. By the end of September, germination was reduced to 2% and, by the middle of November, it had completely ceased. From the foregoing results, it would appear that, in urediospores, prolonged retention of viability is not generally the rule and that the period of viability may be markedly reduced by low temperatures.

Under constant environmental conditions, if they are at all favourable, urediospores may remain viable much longer than indicated above. Peltier (150, 152) stored urediospores under conditions of different constant temperatures and relative humidities and found that the longevity of the spores depended greatly on the combined influence of temperature and humidity. At the end of one year, he (152) obtained 30% germination in spores kept at a temperature of 41° F. and a relative humidity of 49%. At all humidities used, the longevity of the spores decreased as the temperature increased, and at all temperatures the spores remained viable longest at medium humidities. Raeder and Bever (168) found that the urediospores of stem rust retained their viability longer than those of stripe rust or of leaf rust of wheat, being viable at a relative humidity of 49% and at a temperature of from 48.2° to 55.4° F. for 128 days. In the laboratory, it has now become common practice to store urediospores of stem rust at a temperature of about 40° F. and a relative humidity of about 50%. Under these conditions, a high percentage of the spores remain viable for from 6 to 9 months.

The chances of urediospores surviving the winter in Western Canada are probably greatest for those spores that are produced late in the season. Such spores have at least the advantage that they are younger than those produced earlier and are exposed a shorter time to the vicissitudes of the weather. Moreover, if they are produced shortly before temperatures become too cool to permit spore production, they are probably better adapted to withstand low temperatures that occur before snow arrives to protect them. Melander (137) showed that urediospores that had been hardened by exposure for 10 days to temperatures just above the freezing point withstood exposures to temperatures of from -20° to -40° F. better than non-hardened spores, although very few spores of either class were able to survive long exposure to such low temperatures. Air temperatures of this order are not infrequent in Western Canada during the winter. Dry snow, however, is an effective insulator and, on days when such temperatures prevail, the temperature under a snow cover of 12 inches or more may be from 20° to 30° F. higher than the air temperature. At Winnipeg, in 1932, Thomson (216) found that, during January and February, the mean temperature of the surface soil under a snow cover was approximately 20° F., while on a few days during that period the air temperature dropped to -30° F. Under a cover of snow the spores are, therefore, afforded a considerable degree of protection from extremely low temperatures.

The critical periods for the spores are apparently early winter, before a snow cover is present, and late winter, after it has disappeared. During both these periods in Western Canada frosts and thaws may occur. Roussakov (172) pointed out that a cover of snow on frozen ground favoured overwintering but that light snow and thaws tended to prevent it. Lambert (113) expressed the opinion that, although urediospores may remain viable in the Upper Mississippi Valley throughout the winter, they are killed in the spring at the time of alternate freezing and thawing, as the spores, when moist, will germinate at temperatures below those at which infection can take place. The germ-tubes presumably either wither or are destroyed by frost.

It is possible, at least in some years, for urediospores to remain viable until late winter or early spring in the Upper Mississippi Valley and Western Canada. Bolley and Pritchard (24) found viable spores of stem rust on grass hosts frozen in ice in North Dakota in March, and Freeman and Johnson (67) found that in the winter of 1906-07 spores remained viable under snow at St. Paul, Minnesota, as late as the middle of April. In Manitoba, Jackson (98) collected germinable urediospores, usually from under snow, from October 15, 1919, to the middle of March in the following spring.

For several years, Fraser (66) made collections of urediospores from straw and dead grass in the spring. Most of these collections were made in northern Saskatchewan. Each spring, he found at least one collection that contained viable spores, but the proportion of such spores was usually low, about 1 or 2%; they were usually found beneath the leaf sheaths or glumes of the plants. The number of collections with viable spores was higher in 1922 than in the other years. In two of these collections made at Rosthern on April 24 and May 2, spores germinated to the extent of 6% and 10%, respectively. Spores from each collection were used to inoculate wheat seedlings, with the result that each collection gave rise to two infections, which developed into normal pustules. In the spring of 1929, Simmonds³ made germination tests of urediospores collected on and beneath the leaf sheaths of wheat stems in a sheaf and in a straw pile that had been exposed to weather conditions throughout the preceding winter in the vicinity of Saskatoon. The collections were made on March 30, April 8, 16, 25, and May 4, the spores being taken from beneath leaf sheaths as well as from their outer surface. Eight collections gave positive, 9 gave negative results. In 6 of the 8 collections, there was little more than a trace of germination (0.1 to 0.3%). In the other two, made on March 30 and April 25, the percentage germination was 1.2% and 4.8%, respectively.

In the vicinity of Winnipeg, the usual experience is that urediospores on exposed surfaces of plants lose their viability before the severe winter weather sets in. This is particularly true of spores produced on plants that mature during the regular growing season. It is true also in some years, but not in all, of spores produced on very late sown experimental plots that are still green at the beginning of winter. In most years, spores on such plants lose their germinability completely by the middle of November, although, exceptionally, the majority of them may remain viable for a month later, and upwards of 10 to 15% as late as the beginning of the new year. In such cases, viability is largely or entirely lost by the end of January.

Spores produced in pustules beneath the leaf sheath of plants appear to have a much better chance of survival than those on exposed surfaces, for it is such spores that retain their viability longest, even in occasional years until late winter. By that time, however, traces only of germination have ever been found out-of-doors, and these only in extremely rare instances. Occasional collections of urediospores taken from beneath the sheaths of straw stored in sheaves in the laboratory barn have contained a trace of germinable spores as late as the first week of April, but not beyond that time. In one large pustule found beneath the leaf sheath of a wheat

³ Unpublished data of Dr. P. M. Simmonds, Dominion Laboratory of Plant Pathology, Saskatoon, Sask.

plant, approximately 30% of the spores were found viable at the end of February. Part of this spore collection produced satisfactory infection on wheat seedlings. It would seem that, both under field conditions and under ordinary storage conditions in the vicinity of Winnipeg, urediospores of stem rust lose all viability before the beginning of May. At any rate, numerous germination tests on field collections of urediospores have been made at Winnipeg over a period of years during the first two weeks of May, but in no case have viable spores been found.

It must be admitted that the collections of spores tested for germination were made in a limited area, and the number of spores involved in the tests represented only an infinitesimal proportion of the number present in that area at the beginning of winter in any given year. Consequently, it would be hazardous to say that even here or elsewhere in Western Canada urediospores never survive later than the first week of May.

Probably the most likely place for the long survival of urediospores would be in stooks or stacks of unthreshed grain left in the field all winter. During the present investigation, a favourable opportunity was presented once for observing the result of having vast numbers of spores, produced in the previous year, liberated into the atmosphere during early summer. This happened in 1928. A severe epidemic occurred in 1927, and, as there was much rainfall during the summer and autumn, the crop matured exceptionally late, and harvesting was much delayed, so that in many areas a considerable amount of grain was left unthreshed in stook or in stack in the field during the winter. When seeding was finished in the following spring, threshing operations were resumed, and consequently many urediospores were thus liberated into the air during late May and early June. For example, slides exposed in south-eastern Saskatchewan indicated that there was a very considerable number of spores present at that time. Moisture conditions were favourable for infection, although the temperature in June was 2 or 3 degrees below normal, averaging about 57° F. This is too low a temperature for rapid rust development, but not too low for infection and slow rust development. It would be expected that, if infections did occur during late May and the first half of June and their development was retarded by the cool weather, they would have given rise to pustules when warmer weather arrived in late June and early July. Field infections might, therefore, have been expected to appear in this year as early as usual, or even earlier. Actually, however, the first infections appeared in the field later than usual, on July 9 in Manitoba and not until July 20 in Saskatchewan, a circumstance clearly due to the lack of viable inoculum in the early part of summer.

Infections of Doubtful Origin

It is true that one or two instances are known of stem rust being found present on a few wheat plants growing far distant from any other known field infections. The inference would naturally be that these infections had their origin in overwintered stem rust. One such case was found by Dr. G. B. Sanford at Rosthern, Sask., on July 18, 1926. Secondary infections were present, so that probably the initial infection occurred about the first of July. Stem rust was first found in southern Manitoba on June 30 and in south-eastern Saskatchewan on July 14. A careful

search for infections on grasses growing in the vicinity of Rosthern was made by Dr. Sanford, but none was found. As wind-borne spores were present during the last week of June in south-eastern Saskatchewan, there is the bare possibility that some of these spores were carried as far north as Rosthern, although none were detected at that time on the slides exposed at Saskatoon, about 40 miles farther south. If that happened, such spores were probably responsible for the initial infection. A light rain fell in northern Saskatchewan on June 28, so that conditions for spore germination were probably more favourable there than in southern Saskatchewan where the weather during the last week of June was warm and dry. Whatever may be the correct conclusion concerning this case, and one or two other doubtful ones, the evidence is not conclusive that the rust overwintered.

Actually, the survival of urediospores during the winter is of no significance with respect to the overwintering of stem rust unless the spores remain viable far enough into the spring to permit infection in the new growth of grasses or in the young cereal plants. If overwintering of stem rust does occur, one would expect to find infections on susceptible grasses earlier in the season than on cereal crops; for, with the grasses, the new growth occurs in immediate proximity to the plants on which the disease was present in the previous year and in or on which the fungus might be expected to overwinter. Furthermore, new growth usually appears earlier in the grasses than in the cereals, and hence presents an opportunity for earlier infection. It is, therefore, rather surprising that, although during the last 21 or 22 years careful observations have been made on grasses in Western Canada by different workers, infection has scarcely ever been found on them earlier than on cereals, and never under circumstances which would give grounds for the suspicion that the infections arose as a result of the overwintering of the fungus. From a consideration of the evidence available, it must be concluded that overwintering is not a significant factor in Western Canada in the initiation of stem-rust infections in cereal crops, although the possibility of some infections arising from this source in an occasional year cannot be categorically denied.

WIND-BORNE SPORES AS A SOURCE OF INFECTION

The importance of wind-borne⁴ spores in the initiation of stem-rust epidemics is now well established for certain cereal-producing areas. In such areas as the Amur region in Eastern Asia (183), the Plains of India (31, 131, 132, 134, 135), and the Cape Province, South Africa (223), where stem rust is not known to survive in its uredial stage from year to year and susceptible species of barberry are not present, initial infections are dependent entirely on wind-borne spores. Probably the same is true of Egypt (138, 163). In areas where susceptible species of barberry are present, there is always some difficulty in determining to what extent wind-borne spores—as opposed to spores produced on barberry locally—are responsible for early infections, or how much infected barberry contributes to the development of an epidemic. Such an area is the Upper Mississippi Valley in the United States. There is considerable evidence that here, in some years at least, inoculum is carried by air currents from southern to

⁴ The dissemination of rust spores is, under natural conditions, almost wholly by winds, or air currents, so that practically all spores might be designated as wind-borne; but, in this paper, the term is applied to spores that are transported by winds, or air currents, relatively long distances.

northern States (67, 93, 94, 113, 156, 157, 158, 192, 193, 195, 198, 209, 226). Apparently in early summer there is the possibility that upper air currents (4,000 feet elevation) over the United States may carry spores from New York, Pennsylvania, and other eastern States to Texas, Oklahoma, and Kansas, as well as from the latter States northward and eastward (93). It appears that, in South-eastern and Central Europe, also, there is, in addition to inoculum from barberry, a northward drift of inoculum, at least in some years, and outbreaks of stem rust have been attributed, in part at least, to wind-borne spores (12, 69, 178, 179, 181, 182, 187). Even in Australia, a country in which stem rust survives in the uredial stage from year to year, there is a drift of spores from the earlier, more northerly grain-growing areas to the later areas further south (232). A review of the literature relative to the aerial distribution of *Puccinia graminis* and other plant pathogens is given in a previous paper (45).

To gain information as to the part that wind-borne spores play in the initiation and subsequent spread of stem rust in Western Canada, a study was undertaken to ascertain the relative prevalence of spores in the air at different points during the summer months. For this purpose, use was made of glass slides exposed near ground level and during aeroplane flights. If stem-rust spores could be detected in the air at least a week or two earlier than infections occurred in the field, there would be, in the absence of any known local source of inoculum, strong circumstantial evidence that the early infections at least were caused by wind-borne spores.

Evidence of Stationary Slide Exposures⁵

The exposure of glass slides or Petri dishes, or the use of special devices to detect micro-organisms in the air has been resorted to at one time or another by different investigators. Owing to the facility with which they can be exposed and examined, glass slides have been much used. As early as 1882, Ward (228), in his study of the coffee rust, exposed slides coated with vaseline; and, in 1886, Millardet, according to Ducomet (54), exposed slides smeared with oil, and found that within a period of 24 hours as high as 32,000 mildew spores fell on 1 square decimeter of surface. Much information concerning the spread of cereal rusts has been procured by means of the slide-exposure method, particularly by Stakman and others associated with him (192, 193, 196, 202, 203) in epidemiological studies of stem rust in the Mississippi Valley, and by Shitikova-Roussakova (183) in the Amur Region of Eastern Asia. Others (2, 38, 67, 72, 100, 110) have adopted different devices to detect rust spores in the air.

In the present study, microscope slides smeared on one side with vaseline were exposed in a weather-vane type of spore-trap (Figure 3) at selected stations in each of the three Prairie Provinces. After exposure, the slides exposed in Saskatchewan and Alberta were returned to the Saskatoon Laboratory, and those exposed in Manitoba to the Winnipeg Laboratory, where they were examined under the microscope (Figure 4) and a record was made of the number of spores present on 1 square inch of slide surface. At some stations the slides were exposed for 24 hours, at others for 48 hours, and at two or three others for a somewhat longer time.

⁵ This phase of the work was a co-operative study carried on by the Dominion Laboratory of Plant Pathology, Saskatoon, Sask., and the Dominion Laboratory of Plant Pathology, Winnipeg, Man.

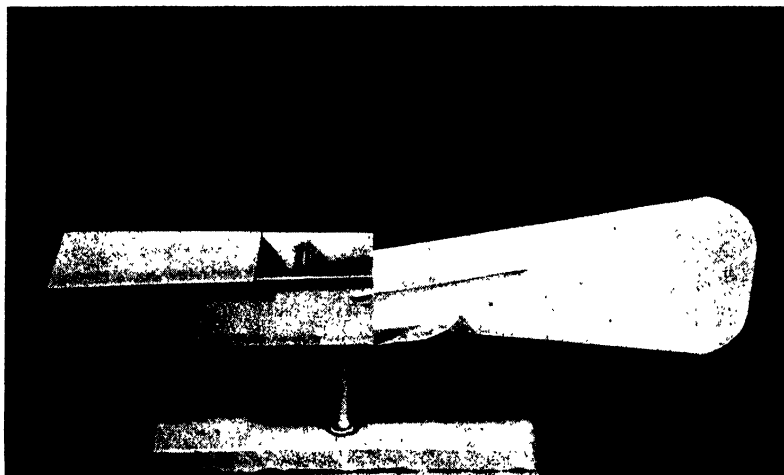


FIGURE 3. Stationary spore-trap, consisting of a galvanized sheet-iron case with sliding top and weather-vane tail, supported on a short iron shaft about which the trap can freely rotate. The slide is held in a vertical position, approximately equidistant between the top and bottom, by means of two U-shaped fixtures, one of which is soldered to either side of the trap.

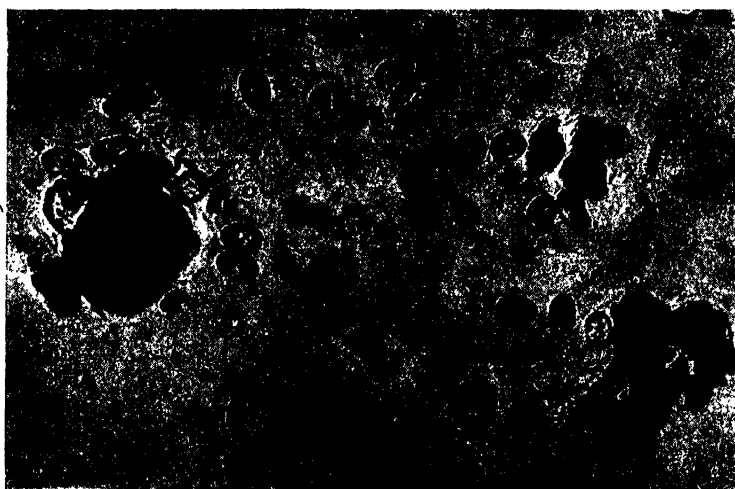


FIGURE 4. Urediospores of stem rust on a vaselined slide that was exposed in a stationary spore-trap for 24 hours at Winnipeg during the height of the 1935 stem-rust epidemic. Magnification, 120 app.

At most of the stations the exposures were begun on June 1, but at some, particularly in Alberta, where stem-rust infection appears late in the season, exposures did not commence until July 15. As a rule, the exposures were discontinued at the end of August. From 1926 to 1929, exposures were made at 5 stations in each province, but after 1929 the number of stations was reduced. Those at which exposures were made each year during the whole period 1926-1938 are as follows: Morden, Winnipeg, Brandon, in Manitoba; Indian Head and Saskatoon, in Saskatchewan; and Edmonton, in Alberta (Figure 1).

TABLE 2.—NUMBER OF STEM RUST UREDIOSPORES INTERCEPTED EACH 2-DAY PERIOD BY 1 SQUARE INCH SURFACE OF GLASS SLIDE EXPOSED AT MORDEN, WINNIPEG, AND BRANDON, MAN., AND INDIAN HEAD AND SASKATOON, SASK., FROM JUNE 11 TO JULY 20 EACH YEAR, EXCEPT 1936, FROM 1926 TO 1938

	1926					1927					1928					1929				
	Morden	Winnipeg	Brandon	Indian Head	Saskatoon	Morden	Winnipeg	Brandon	Indian Head	Saskatoon	Morden	Winnipeg	Brandon	Indian Head	Saskatoon	Morden	Winnipeg	Brandon	Indian Head	Saskatoon
June 12	0	0	0	0	0	0	0	0*	0	0	0	1	0	0	0	0	0	0	2	1
June 14	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	0	0	1	0
June 16	0	0	0	0	0	0	0	1	0	0	0	0	2	1	24	133	0	0	0	0
June 18	0	0	0	0	0	0	0	0	0	5	0	0	1	3	2	174	193	68	0	0
June 20	0	0	0	0	0	0	0	0	2	13	0	0	0	4	2	0	0	0	0	0
June 22	0	0	0	0	0	0	2	4	0	0	0	0	0	0	0	0	0	0	0	0
June 24	0	0	0	1	0	0	3	3	0	0	0	0	2	1	0	0	0	0	2	0
June 26	2	3	0	2	0	5	31	0	0	0	1	0	2	1	0	0	0	1	24	0
June 28	5	0	0	3	0	9	20	0	0	0	0	1	0	1	3	15	1	0	2	0
June 30	0	0	0	3	0	0	4	0	1	0	0	0	0	4	7	0	0	0	1	0
July 2	0	0	0	0	0	0	0	5	2	1	0	0	0	0	0	1	0	0	1	1
July 4	0	2	0	0	0	13	38	9	0	36	0	0	0	4	0	1	2	2	0	0
July 6	0	1	0	1	0	7	22	0	0	2	0	0	0	11	2	0	4	0	1	4
July 8	0	4	0	2	0	0	18	36	0	0	0	0	1	0	7	0	3	1	16	1
July 10	1	1	0	1	0	8	0	0	0	0	0	0	2	0	2	3	481	0	5	2
July 12	3	2	0	1	0	0	4	0	0	2	0	2	0	6	0	1	283	0	1	3
July 14	64	24	0	1	0	5	3	22	0	0	0	45	3	8	1	2	31	0	2	0
July 16	152	5	0	8	1	7	1	7	0	0	0	0	0	8	7	3	117	0	4	2
July 18	980	15	4	1	3	0	10	3	1	0	1	4	2	3	11	3	37	5	6	1
July 20	945	0	1	7	2	9	254	2	15	0	2	6	5	8	3	199	2983	26	22	0
	1930					1931					1932					1933				
	Morden	Winnipeg	Brandon	Indian Head	Saskatoon	Morden	Winnipeg	Brandon	Indian Head	Saskatoon	Morden	Winnipeg	Brandon	Indian Head	Saskatoon	Morden	Winnipeg	Brandon	Indian Head	Saskatoon
June 12	0	0	0	0	0	0	0	3	0	0	0	6	4	0	0	0	2	0	0	0
June 14	0	0	0	0	0	0	0	2	0	0	3	4	5	0	0	0	0	0	0	0
June 16	0	1	0	0	0	0	2	3	0	0	2	3	3	0	0	0	0	0	0	0
June 18	0	1	0	0	0	0	1	0	0	0	3	0	9	0	0	0	0	0	0	0
June 20	1	1	0	0	0	0	0	1	0	0	1	0	4	0	0	0	0	0	0	0
June 22	0	1	1	0	0	1	1	7	0	0	1	1	3	0	0	0	0	0	20	2
June 24	0	2	0	0	0	0	0	9	0	0	1	1	1	0	0	1	0	0	0	0
June 26	0	0	0	0	0	3	0	1	0	0	1	0	0	0	0	0	1	0	0	0
June 28	2	0	1	0	0	5	2	2	0	0	1	0	1	0	0	2	2	0	4	0
June 30	1	0	1	0	0	0	2	2	0	0	4	1	0	0	0	0	0	0	8	4
July 2	0	9	6	11	4	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
July 4	0	7	15	4	0	2	0	0	0	0	1	0	1	0	0	0	2	0	0	0
July 6	1	0	0	7	0	0	0	8	0	0	0	0	8	1	0	0	0	0	0	0
July 8	7	8	0	1	3	0	3	0	0	0	4	8	12	3	2	0	0	2	4	0
July 10	0	5	0	1	101	22	21	9	0	0	0	1	4	0	2	1	0	1	4	0
July 12	111	8	0	9	2	39	0	52	0	0	4	10	1	15	0	2	2	0	4	0
July 14	22	178	1	28	6	36	2	1	0	0	59	3	7	9	15	2	2	0	0	0
July 16	171	659	74	19	0	0	8	11	0	0	8	4	8	0	0	0	1	0	0	0
July 18	92	7	1	18	1	207	0	2	61	0	271	22	1095	94	0	2	5	9	0	0
July 20	0	32	112	168	0	27	9	10	11	11	117	93	18	22	0	20	10	12	0	0

* In 1927, the slides were exposed at Killarney, Man., up to July 8, and at Brandon from July 13, onward.

TABLE 2.—NUMBER OF STEM RUST UREDIOSPORES INTERCEPTED EACH 2-DAY PERIOD BY 1 SQUARE INCH SURFACE OF GLASS SLIDE EXPOSED AT MORDEN, WINNIPEG, AND BRANDON, MAN., AND INDIAN HEAD AND SASKATOON, SASK., FROM JUNE 11 TO JULY 20 EACH YEAR, EXCEPT 1936, FROM 1926 TO 1938—*Concluded*

	1934					1935					1937					1938				
	Morden	Winnipeg	Brandon	Indian Head	Saskatoon	Morden	Winnipeg	Brandon	Indian Head	Saskatoon	Morden	Winnipeg	Brandon	Indian Head	Saskatoon	Morden	Winnipeg	Brandon	Indian Head	Saskatoon
June 12	0	0	0	0	0	0	0	0	0	0	1	4	0	0	0	1	0	1	0	0
June 14	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	29	5	8	0	0
June 16	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	18	0	0	0	0
June 18	0	2	0	0	0	0	0	0	2	0	1	2	0	0	0	29	0	0	0	0
June 20	0	2	0	0	0	0	0	0	0	0	1	2	0	0	0	43	18	9	0	0
June 22	0	3	1	0	0	0	0	0	0	0	2	8	7	0	0	3	10	0	0	0
June 24	0	0	0	0	0	22	249	6	0	0	2	13	-	0	0	10	0	2	0	0
June 26	0	2	0	0	0	6	52	3	0	0	0	2	-	0	0	1	1	2	0	36
June 28	0	1	0	0	0	0	10	0	12	0	0	1	0	0	0	18	86	17	84	0
June 30	0	0	0	0	0	84	54	31	12	0	2	0	0	0	0	59	328	2	4	0
July 2	0	0	0	0	0	61	29	22	0	0	0	1	0	0	0	25	5	7	12	0
July 4	0	0	1	0	0	9	19	7	0	0	18	1	24	0	0	23	0	2	0	-
July 6	3	0	0	0	0	4	5	0	19	0	110	190	80	0	0	14	4	5	18	12
July 8	13	15	16	9	0	11	1	0	0	0	10	3	1	0	4	580	3	81	126	0
July 10	0	3	10	5	0	33	3	23	0	0	125	82	3	5	15	900	140	224	432	0
July 12	6	1	0	0	0	195	15	23	11	0	170	0	4	32	0	6120	247	430	1204	80
July 14	8	9	2	0	0	-	13	9	10	0	100	13	48	0	0	9420	113	395	810	160
July 16	64	4	2	58	8	-	1175	16	7	6	8	2	38	48	0	3540	390	360	1015	0
July 18	36	1086	7	11	0	-	385	73	21	4	3300	44	210	0	0	810	880	490	1524	50
July 20	17	1	3	47	29	3620	504	595	450	5	6000	232	630	0	0	146	200	595	72	4230

* In 1927, the slides were exposed at Killarney, Man., up to July 8, and at Brandon from July 13, onward.

No one needs to be reminded that "the wind bloweth where it listeth," and, as a consequence, no great regularity could be expected with respect to time and place of the first appearance and number of spores on the slides. Moreover, the location of the station, whether in a depression or in an exposed area, and the actual location of the spore-trap at the station, no doubt influenced to some extent the number of spores that came into contact with the slides. Furthermore, it is almost too much to expect that a small glass slide would detect the first spores to arrive in any district. On the assumption that spores in the first 1,000 feet of atmosphere are uniformly distributed, the presence of 1 spore on 1 square inch of slide exposed for 24 hours would indicate that somewhat more than 760,000,000 spores had passed through a vertical plane extending laterally 1 mile and to a height of 1,000 feet. The fact, however, that 1 spore on a slide may indicate the presence of such a large number in the atmosphere gives added significance to the low number of spores on some of the slides (Table 2). With a lesser number of spores present, a slide might or might not detect them. At best, therefore, the data furnished by the slides can only be regarded as an indication of the relative number of spores present and an index, possibly, of the dates on which the number was in excess of the minimum usually necessary for detection. For the same reason, the dates

on which 1 or more spores were first detected by slides exposed at different stations do not necessarily indicate the earliest dates on which spores were present in the atmosphere over the districts represented by the stations.

Number of Spores Intercepted. Data collected during the 13-year period 1926 to 1938 on the daily number of spores intercepted, if presented with any degree of completeness, would occupy an undue amount of space, and no very satisfactory scheme has been found of summarizing them in the form of a table. A part of the data is contained in Table 2, which gives the number of urediospores of stem rust per square inch intercepted each 2-day period by slides exposed at Morden, Winnipeg, and Brandon, in Manitoba, and Indian Head and Saskatoon, in Saskatchewan, between June 11 and July 20 for the period 1926-1938 (except 1936, a light rust year, which is omitted to conserve space). As at Edmonton practically no spores were intercepted by the slides exposed before July 20, the results for that station are omitted entirely. The interval from June 11 to July 20 was selected for the reason that before June 11 very few spores were intercepted by the slides at any of the stations and after July 20 locally produced spores were usually becoming so plentiful, particularly in southern Manitoba, as to cause an appreciable increase in the number of spores intercepted by the slides, and thus to obscure evidence of low to moderate influxes of wind-borne spores. It is not proposed to discuss at this point the data presented in Table 2, as these data will be drawn upon in different parts of the subsequent discussion. Attention, however, may be called to the occasional sudden increases in the number of spores intercepted by the slides at one or more of the stations, followed usually within 2 or 3 days by an equally sudden decrease. These sudden increases in the spore population of the atmosphere constitute the so-called "spore showers," and they have an intimate relation to the development of stem rust in the areas where they occur.

Viability of Early Spores. In regard to the viability of the early arriving spores, it may be said that any spores intercepted during the first week of June in any year were generally somewhat bleached in appearance, and failed to germinate when the slides bearing them were placed under conditions favourable for germination. There is not much likelihood that such spores were capable of causing infection, although it should be mentioned that germination tests of viable-looking spores somewhat later in the season were not very successful, probably because the spores became embedded in the vaseline—a circumstance that prevented their contact with water when they were placed in a saturated atmosphere. From time to time, however, germination was secured; and, in fact, occasionally during humid weather, the spores on some slides germinated while the slides were yet exposed.

To remove any uncertainty as to the viability of spores found in the atmosphere before infections appeared in the field during the later years of the investigation, a different method was adopted. An attachment, which accommodated and held firmly the bottom of a Petri dish, was fastened to an automobile in such a manner as to hold the Petri dish bottom in a vertical position and facing in the same direction as the automobile. When a survey trip during the latter part of June was to be made, a thin fresh layer of plain agar was poured over the bottoms of several dishes and

the covers replaced. The dishes were taken along on the trip, and from time to time one of them was exposed by removing the cover and fixing the bottom to the attachment. Not infrequently the spores germinated before the dishes could be brought back to the laboratory and examined. The results obtained by this method showed clearly that, from 1931 to 1938, viable spores were present in Manitoba for a week or two each year before any infections occurred in the field.

Relation of Data to Pattern of Rust Development in the Field. In spite of the evident limitations of the slide-exposure method, the data obtained through the exposure bear a generally recognizable relationship, at least in most years, to the broad pattern of stem-rust development and spread in different parts of Western Canada. For instance, it will be seen from Table 3 that spores in detectable concentrations were present at Morden and Winnipeg, Man., usually earlier than at Indian Head, Sask., always considerably earlier than at Saskatoon, Sask., and generally a month or more earlier than at Edmonton, Alta. It will be recalled (Table 1) that a similar westward lag occurred in the first appearance of field infection. Infections appear on the crops in southern Manitoba from a few days to upwards of a month earlier than in Saskatchewan, and from a month to two months earlier than in Alberta.

Furthermore, a comparison of Tables 1 and 3 will show that, as a rule, stem-rust urediospores were present in the atmosphere at the different stations in Manitoba and Saskatchewan from a few days to a week or more before any infections occurred in the field, and in Alberta generally for a much longer time. The two or three evident exceptions can be explained by the fact that, in Table 1, the dates on which the first infections appeared in a province apply to the province as a whole, no matter where the infections occurred. For example, in 1926, the first infections on wheat in Alberta appeared on August 17 but spores were not detected by the slides exposed at Edmonton until August 24. However, slides exposed at Lethbridge and Olds, Alta., detected spores on August 10 and 13, respectively, so that spores were present in the province at least a week before any infections were found in the field. Or again, in 1938, the spore shower that occurred in Manitoba on June 13 and 14 reached the eastern margin of Saskatchewan but did not extend as far west as Indian Head. No spores were intercepted at that station until towards the end of June, but infections appeared along the eastern edge of the province as early as June 21. Infections were, therefore, present in the crop about a week before spores were intercepted by the slides exposed at Indian Head. Apparently, however, the slides exposed at Indian Head in 1937 failed to detect spores in the air before infections appeared in the field, for a few infections were found at that station on June 28, but no spores were detected by the slides until July 4. Spores, however, were present in the air over Manitoba considerably earlier, for a well defined spore shower occurred on June 13 and 14. This seems to be the only instance where, in a particular locality, the slides failed to detect the presence of spores before infection appeared in the field.

TABLE 3.—DATES ON WHICH STEM-RUST SPORES WERE FIRST DETECTED ON SLIDES EXPOSED AT MORDEN, WINNIPEG, INDIAN HEAD, SASKATOON, AND EDMONTON, FROM 1926 TO 1938

Year	Morden	Winnipeg	Indian Head	Saskatoon	Edmonton
1926	June 4	June 5	June 24	July 16	Aug. 24
1927	June 25	June 1	June 19	June 17	Aug. 3
1928	June 5	June 6	June 2	June 16	July 20
1929	June 16	June 7	June 12	June 4	July 23
1930	June 6	June 9	July 1	July 1	July 27
1931	June 6	June 9	July 17	July 19	July 18
1932	June 7	June 3	July 5	July 7	July 27
1933	June 28	June 12	June 29	June 21	Aug. 11
1934	July 7	June 10	July 7	July 14	July 29
1935	June 6	June 19	June 26	July 17	Aug. 4
1936	June 2	June 3	June 21	June 23	July 20
1937	June 9	June 1	July 4	July 8	Aug. 9
1938	June 3	June 1	June 28	June 26	July 15*

* Spores were present on the first slide exposed (July 15).

It would not be expected that the earliest arriving spores generally produced infections. As a matter of fact, in some years, as much as three or four weeks elapsed between the first trace of spores on the slides and the earliest occurrence of field infections. The occurrence of infection, of course, depends on the viability of the spores themselves and on weather conditions after their arrival. How soon, after infection takes place, pustules appear on the plants depends largely on subsequent temperature and light conditions. It is improbable that the stage of crop maturity influences the course of rust development. These aspects will be considered in later sections of this paper. What is worthy of notice here is that, in every year of the investigation, spores were almost invariably present on the slides exposed in each of the three provinces before any infections could be found on the crops or native grasses. It is, therefore, reasonable to conclude that the wind-borne spores were responsible for the infections.

Long-Distance Spore Dissemination. From the slide-exposure studies, many instances could be cited of the long-distance dissemination of stem-rust spores, but two or three will suffice. In 1927, the slide exposed at Beaver Lodge in the Peace River Valley, Alberta, during the week ending July 28 intercepted 3 urediospores per square inch. No spores were found for the next two weeks, but the slide exposed during the week ending August 18 intercepted 77 spores per square inch. Up to 1927, stem rust was unknown in the Peace River Valley, and it was not reported again until 1938. It is, therefore, most improbable that these spores were of local origin. Rather would it appear that they had come from areas quite far distant. Field infections only began to appear in the vicinity of Edmonton after the middle of August, and, at the end of July, were largely confined to eastern Saskatchewan, so that the spores found at the end of July at Beaver Lodge probably did not originate nearer than eastern Saskatchewan or the International Boundary, and those found at the middle of August, nearer than western Saskatchewan, distances, respectively, of at least 700 and 300 miles.

In 1929 a heavy spore shower occurred during June 16 and 17 in southern Manitoba. It was heavier at Morden and Winnipeg in the eastern part of the province than at Brandon in the western part, and it did not extend as far west as Indian Head and Saskatoon. No infection was present in Western Canada, and, according to information received from the United States Department of Agriculture, the northern limit of stem-rust infection in the Mississippi Valley on those dates can be indicated by a curved line passing through central Colorado, northeastwardly through Nebraska into south-eastern South Dakota, and thence south-eastwardly into central Illinois. Only traces of stem rust were present along this northern boundary. At Winnipeg, however, the slide exposed on June 16 intercepted 133 spores and the slide exposed on June 17 intercepted 193 spores per square inch. At two or three other points in eastern Manitoba, comparable numbers of spores were intercepted on June 17. Evidently these spores must have originated somewhere south of the line previously mentioned, and must have, therefore, been carried northward for 500 miles or more. Practically no spores were intercepted on June 18, although throughout the day the wind continued in the same direction. Apparently most of the spores were washed out of the air by rain that occurred on that date from eastern Nebraska northward to Manitoba.

The epidemic of 1935 offers another example of the long-distance spread of stem-rust spores. The first spore shower of that summer occurred during a period of south wind, from June 23 to 25. The shower was quite heavy, for the slide exposed at Winnipeg on June 24 intercepted 240 urediospores per square inch. Stem rust was then just appearing in the southern part of Minnesota and South Dakota⁶, a distance of approximately 400 miles from Winnipeg. As at that time only a trace was present in those areas, it is very probable that the spores reaching Winnipeg originated still farther south, and, consequently, the distance travelled by them was perhaps considerably greater than that just indicated.

That urediospores of stem rust are carried far north beyond the cultivated region of Western Canada is indicated by the fact that Newton, late in the summer of 1936, found stem rust on volunteer wheat plants growing at Churchill on Hudson Bay, about 600 miles north of Winnipeg (144); and, in September, 1940, on *Hordeum jubatum* at Hay River, on the western end of Great Slave Lake, about 500 miles north of Edmonton⁷. Churchill is about 500 miles from the nearest cereal-growing area, and Hay River about 350 miles. The probability is that, in both instances, the infections were caused by wind-borne spores. Several times during the summer of 1936 the high and low air-pressure areas (See page 000) were in a favourable position to bring spores by a southerly wind to Churchill from infected grain-growing areas. Slides exposed at Norway House, 275 miles north of Winnipeg, have shown that spores in large numbers (Table 4) are sometimes present in the air that far north, and it is probable that spores in considerable numbers are occasionally carried as far north as Churchill,

⁶ Compare U.S.D.A. Plant Disease Reporter 19 : 154. 1935.

⁷ Newton, Margaret. Additions to the fungus flora of the McKenzie River Basin. In Annual Report of the Canadian Plant Disease Survey, 1940. Division of Botany and Plant Pathology, Canada Dept. Agr., Ottawa 20 : 100-102. 1941.

or even farther. It would seem probable, too, that, in 1940, spores from the grain-growing area of Western Canada were carried north-westerly as far as Great Slave Lake.

Evidence of Aeroplane Slide Exposures

In addition to the stationary exposures, slides were exposed during aeroplane flights. The purpose of these exposures was to supplement the data furnished by the stationary slides and to give some indication of the concentration of spores in the air at different altitudes, as well as to ascertain whether or not they were present over northern areas where it was not possible to expose stationary slides. It was only through the generous co-operation of the Branch of the Royal Canadian Air Force stationed at Winnipeg that this phase of the work was made possible. These exposures were continued from 1925 to 1931. An account of each year's results is contained in the Reports of the Dominion Botanist, Department of Agriculture, Canada, for those years, and, consequently, a discussion of the results obtained need not be given here in detail.

A considerable number of studies have been made by different investigators to gain information concerning the fungal and bacterial population of the atmosphere, and a good deal has been learned concerning the identity of the organisms present and their relative numbers. Reference to such studies has been made in another publication (45). From them it is evident that micro-organisms may be present even to a height of three miles or more above the surface of the earth, although at high levels they are very much less numerous than at lower levels. Stakman, Henry, Curran, and Christopher (203), in an attempt to discover to what height stem-rust spores were present in the air over different parts of the Mississippi Valley, found various kinds of spores up to an altitude of 16,500 feet—the highest level at which exposures were made. Urediospores of stem rust caught at 7,000 feet germinated readily. These investigators used several different types of spore-trap, one of which was adopted for the present work.

In the present work, the exposures were made largely during forest-patrol flights in Manitoba, in the months of July and August, but not according to any definite schedule. The duration of most of the exposures was 15 minutes, but some slides were exposed for only 5 or 10 minutes. Each exposure was made at a definite altitude, the range being from 1,000 to 7,000 feet. In Manitoba, exposures were made from 1925 to 1929 over areas lying east of the southern extremity of Lake Winnipeg, and others over areas at the northern extremity of Lake Winnipeg, and, from 1926 to 1929, in the vicinity of Cormorant Lake, about 90 miles west-by-north of the latter locality. No exposures were made in Saskatchewan, but some were made at High River, Alberta, in 1925 and 1926. The type of spore trap used is illustrated in Figure 5.

As the slides were exposed for a relatively short time, it would appear that spores would have to be fairly plentiful in the air before any considerable number of them would be intercepted during an exposure. As a matter of fact, the number was usually low, particularly on those slides exposed in late June and early July. On many of these no spores were found at all. Later in the season, however, the number occasionally was surprisingly high. For the purpose of this study, the exposures of most

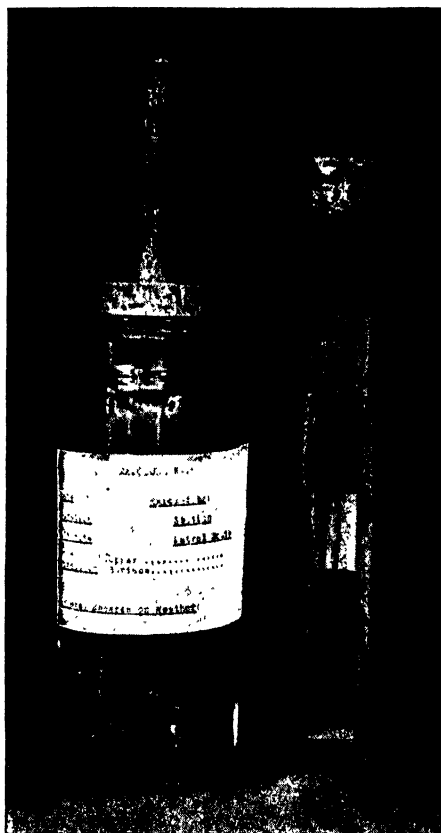


FIGURE 5. Spore trap used in making slide exposures during aeroplane flights. Two glass slides placed end to end are held in position on the front side of a wooden paddle by means of two narrow grooves that face inwards. A thin smear of vaseline covers the exposed face of each slide. The handle of the paddle projects through a perforated stopper that fits tightly into the mouth of the bottle. For an exposure, the paddle is removed from the bottle and held with the slide facing in the direction of flight for a designated length of time.

interest are those made at Cormorant Lake. This lake is more than 300 miles north of Winnipeg and is separated from the nearest cultivated area by a region of forest and lakes approximately 150 miles in width.

Northward Dispersal of Spores. The results of the exposures in the Cormorant Lake region are given in Table 4, and furnish some evidence of distant northward dispersal of stem-rust spores. Relatively few spores were intercepted by the slides exposed in 1926, a light rust year, but in 1927, a year of late crops and heavy stem rust, spores in this region were much more numerous. The number was considerably less in 1928 and in 1929, both comparatively light rust years.

It cannot be said with absolute certainty that these spores were not of local origin, as Cormorant Lake is not easily accessible, except by aeroplane, and no observations were made to determine whether or not stem rust was present on native grasses growing in the vicinity. There is little likelihood, however, that such a high concentration of spores in the air, as indicated by

the number on some of the 1927 slides, could have originated locally, if, indeed, any local infection was present at all. Rather would it appear that the source of these spores was the rusted grain fields of southern Manitoba. In 1928, stem-rust spores were caught by the exposures made between July 13 and 19. The first traces of stem rust in the field appeared in the southern part of the province between July 9 and 12. These few scattered pustules would be entirely inadequate to produce sufficient inoculum to account for so many spores being present in the air more than 300 miles distant. There can scarcely be any doubt that they originated south of the international border. The high and low air-pressure areas (to be discussed later) were so positioned on July 13 and particularly on July 14 as to bring a south wind to northern Manitoba, a fact that seems to support this belief. The same is true of July 29 and August 5, on which 21 and 15 spores, respectively, were intercepted by the slides. In general, it would appear that, when any considerable number of spores were intercepted in that region, their presence may be attributed to dispersal by south winds.

TABLE 4.—THE NUMBER OF STEM-RUST UREDIOSPORES PRESENT PER SQUARE INCH ON GLASS SLIDES EXPOSED FOR 15 MINUTES DURING AEROPLANE FLIGHTS AT CORMORANT LAKE, ON THE DATES INDICATED, AT ALTITUDES BETWEEN 3,000 AND 5,000 FEET

1926	1927	1928	1929
July 12 - 0	July 7 - 0	July 13 - 4	July 13 - 0
July 15 - 0	July 12 - 0	July 14 - 7	July 18 - 0
July 17 - 0	July 17 - 0	July 16 - 2	July 19 - 1
July 24 - 0	July 23 - 0	July 19 - 18	July 20 - 1
July 25 - 1	July 25 - 1	July 27 - 0	July 21 - 0
July 29 - 0	July 29 - 0	July 28 - 0	July 25 - 0
		July 29 - 21	July 28 - 0
		July 30 - 0	July 29 - 1
			July 30 - 0
Aug. 3 - 1	Aug. 11 - 13	Aug. 5 - 15	
Aug. 10 - 0	Aug. 12* - 89	Aug. 8 - 0	Aug. 1 - 4
Aug. 14 - 2	Aug. 12* - 45	Aug. 10 - 0	Aug. 3 - 0
Aug. 17 - 2	Aug. 12* - 3	Aug. 18 - 1	Aug. 4 - 1
Aug. 25 - 1	Aug. 22 - 0	Aug. 20 - 0	Aug. 5 - 0
Aug. 28 - 3	Aug. 24 - 0	Aug. 23 - 4	Aug. 6 - 3
Aug. 31 - 10	Aug. 31 - 113	Aug. 24 - 0	Aug. 11 - 0
		Aug. 25 - 0	Aug. 12 - 0
		Aug. 28 - 0	Aug. 14 - 0
Sept. 1 - 0	Sept. 8 - 181		
Sept. 7 - 0	Sept. 12 - 216		
Sept. 14 - 0	Sept. 16 - 7		

* The three exposures on August 12 were of 5 minutes duration and were made by three different patrols at altitudes of 3,000, 4,000, and 5,000 feet, respectively.

Vertical Distribution of Spores. As rust spores are readily air-borne, it is apparent that upward air currents might carry them to relatively high altitudes. On the patrol flights referred to above, most of the exposures were made at altitudes between 1,000 and 5,000 feet. Within this range, spores did not appear to be more numerous at one altitude than at another.

In order to ascertain the relative concentration of spores in the atmosphere at successively higher altitudes, a series of special flights was made in Manitoba at Portage la Prairie in 1930 and at Winnipeg in 1931. The data are recorded in Table 5. In these flights the pilot made an exposure at the lowest altitude, then rose to the next higher one and made the second exposure, and so on until the highest and last exposure of that series was made. The space of time between the first and last exposure was, therefore, relatively short. In connection with Table 5, it should be recalled that during late July and in August, 1930, a moderate to heavy outbreak of stem rust was present in Manitoba, while in 1931 there was but a light infection. In the latter year, cereal crops ripened early and harvesting operations were well under way by the first week of August.

It would appear from Table 5 that, on those days in which several thousand spores were intercepted by the slides, the concentration of spores was greatest up to 5,000 feet or thereabout. This is evident from the exposures made in late July and in the first half of August. There is no way of determining where these spores originated, but presumably a large proportion of them were produced in Manitoba. The exposures made in June and the first three weeks of July, 1931, show that the distribution of spores in the air was rather uniform to considerable heights during that period, a fact which suggests that the spores had travelled a considerable distance and had become more or less uniformly distributed through the atmosphere.

TABLE 5.—THE NUMBER OF STEM-RUST SPORES PER SQUARE INCH INTERCEPTED BY MICROSCOPE SLIDES EXPOSED AT DIFFERENT ALTITUDES FOR 10 MINUTES ON EACH OF SEVERAL DIFFERENT DATES IN 1930 AND 1931

Date	Number of spores at different altitudes					
	1,000 ft.	3,000 ft.	5,000 ft.	7,000 ft.	10,000 ft.	14,000 ft.
1930						
July 29	756	—	684	—	2	6
Aug. 1	13,920	—	1,440	—	7	16
Aug. 5	24,200	—	7,560	—	108	10
Aug. 8	1,596	—	30	—	21	18
Aug. 12	4,200	—	9	—	19	12
Aug. 13	6,096	—	48	—	21	5
Aug. 14	24,000	—	170	—	36	30
1931						
June 15	12	0	0	0	0	5
June 22	1	1	1	3	3	4
June 29	1	0	1	1	1	2
July 7	3	1	1	0	0	0
July 13	4	4	0	1	1	2
July 20	4	2	0	0	0	1
July 27	6,840	8,760	6,360	1	1	0
Aug. 5	3,685	1,800	9	0	No exposure	No exposure

Horizontal Distribution of Spores. Not much information concerning the horizontal distribution of spores was obtained through the aeroplane-slide exposures, but the few data bearing on this point are in agreement with those of the stationary-slide exposures. From the latter exposures (Table 2), it is abundantly clear that the concentration of stem-rust spores in the atmosphere near ground level varies greatly from place to place and from time to time. The data furnished by the aeroplane exposures, although relatively few, indicate that, at an altitude of approximately 5,000 feet, the horizontal distribution of spores is by no means uniform. For instance, on September 15, 1926, at Lac du Bonnet, which is situated at the southern extremity of Lake Winnipeg, a 5-minute exposure was made at 5,000 feet on each of three different patrol routes. The exposure on one route intercepted ninety times as many spores as either of the exposures on the other two routes. Within the same general region, there was, therefore, a pronounced difference in the number of spores. On July 11, 1929, an exposure at Lac du Bonnet collected three times as many spores as one at Portage la Prairie, 110 miles distant. The reverse result was obtained on July 29, 1930, from two exposures made at Portage la Prairie and one at Lac du Bonnet. At approximately the same altitude, the concentration of spores at Portage la Prairie was nearly one hundred times that at Lac du Bonnet.

PLACE OF ORIGIN OF EARLY WIND-BORNE INOCULUM

If, as is evident from the foregoing discussion, wind-borne inoculum is responsible each year for the initiation of stem rust in Western Canada, the question naturally arises as to where this inoculum originates. Obviously it must originate in an area where the growing season is somewhat earlier than in Western Canada, for, in an area with a later growing season, climatic conditions would undoubtedly prevent stem rust from developing until a correspondingly later date, and hence inoculum would not be available for dissemination. Not only must inoculum be present in the area, but it would seem necessary that it be present in considerable abundance before it could be effectively disseminated long distances. Furthermore, in order that inoculum be introduced into Western Canada, there must be during June and July one or more periods in which the wind is favourable to the introduction of inoculum from whatever area is in question. These restrictive qualifications would seem to limit very largely the area of inoculum origin to the Mississippi Valley.

The first two qualifications would seem to eliminate to a great extent the Pacific Northwestern States and British Columbia as areas of inoculum origin. In the Pacific Northwestern States, a considerable acreage is sown to cereals, but the growing season is usually concurrent with or somewhat later than that of the Upper Mississippi Valley, and hence the former area has no advantage over the latter in respect to earliness of stem-rust development. Furthermore, in the Inland Empire, a large agricultural region lying between the Rocky and the Cascade Mountains, stem rust is rarely of economic importance (85), although it is frequently severe, apparently, in other parts of these States (67). In British Columbia, the cereal acreage is small; the growing season is still later; and stem rust is usually of minor importance, except occasionally in a few localities.

Then, too, the presence of high mountain ranges, running in a general north-to-south direction in both these areas, would tend to interpose a considerable barrier to the spread of inoculum across these ranges, although probably not an insuperable barrier. As is pointed out later, there is a probability that, when inoculum is available in these areas, it can be brought by winds into Western Canada. It is, however, improbable that the early inoculum reaching Western Canada, or indeed in most years, any considerable amount of later inoculum originates in these two areas.

On account of the lateness of the growing season and the scarcity of susceptible grass hosts in the territory lying north of the cultivated area of Western Canada, there is practically no possibility that whatever slight amount of inoculum arises there can be produced early enough to influence in any way the course of the disease in the cultivated area.

As far as Ontario is concerned, the territory lying north of Lake Superior and Lake Huron and extending from Manitoba to the western boundary of Quebec is developed comparatively little agriculturally, and throughout this territory the growing season is later than in Western Canada. Whatever inoculum may develop there is produced too late to initiate early infections and too small in quantity to influence appreciably the amount of infection in Western Canada, even if it did reach this area. The only part of Ontario in which inoculum for early dissemination could arise is the area lying immediately north of Lake Erie and Lake Ontario. In this area, local outbreaks of stem rust originating from infected barberry frequently occur, and in occasional years general outbreaks develop, but it is unlikely that inoculum is ever produced there in sufficient abundance to provide early inoculum for Western Canada. Moreover, as is pointed out later, the occasions on which either early or later inoculum from this area could be carried by winds into Western Canada are extremely rare, if indeed such occasions occur.

The probability of inoculum produced in such eastern States as New York, Pennsylvania, and Ohio, reaching Western Canada seems to be just about as small as it is of inoculum produced in southern Ontario. Still less is the probability of inoculum produced in Quebec and the Maritime Provinces, or the New England States being carried by winds to Western Canada. There is a better possibility of inoculum being carried in from Wisconsin, Illinois, and Michigan, but the most probable source of the early inoculum, as well as of the later arriving inoculum, is the western Mississippi Valley, particularly the more northerly part of it.

As is well known, the Mississippi Valley comprises a vast cereal-growing area, extending from the Gulf of Mexico to the Canadian border, and immediately adjoining Manitoba and eastern Saskatchewan. In it, crops ripen successively later from south to north, so that with favourable weather conditions it would be possible in one season for stem rust to spread from south to north throughout its full length. As mentioned earlier, stem rust overwinters practically every year to a greater or less extent in the extreme south, in the State of Texas, and in some years at least there is definite evidence of the spread of stem-rust spores from southern to northern States (67, 94, 113, 156, 157, 158, 192, 193, 195, 198, 209, 226). This progressive advance has been observed in the field in such years as 1904 (67, 85), 1935 (195), 1937 (199), and 1938 (140). Further-

more, in the northern States, barberry becomes infected every year, so that even in a year when there may be little or no northward drift of spores from the south, inoculum may spread from infected barberries (57, 102, 141, 144, 149, 169, 189, 191, 192, 205) to cereal crops in this area, and inoculum produced on these crops may then spread northward into Western Canada. It may be mentioned here, however, that owing to the extensive eradication of the common barberry in the northern States, this source of infection is continually becoming of less importance (94, 156, 157, 195, 211) for both areas.

In the present investigation, definite evidence of northward spread of inoculum from the Mississippi Valley into Western Canada has been obtained, but as this evidence can be more conveniently presented in connection with the discussion on the relation of wind to the spread of stem rust, it is reserved for that section of this paper. The inoculum arriving in Western Canada in June and early July apparently may come from as far south as southern Iowa, or possibly even from farther south, but the bulk of the later arriving inoculum probably originates in the more northerly States of the Mississippi Valley. A comparison of the severity of the stem-rust outbreaks in the northern Mississippi Valley and Western Canada over a period of years and of the predominating physiologic races of the rust present in different years in the two areas, seems to support the conclusion that outbreaks in Western Canada are largely northward extensions of outbreaks in the northern Mississippi Valley.

COMPARISON OF STEM RUST SEVERITY IN THE UPPER MISSISSIPPI VALLEY AND WESTERN CANADA

From the fact that Western Canada lies immediately north of the Mississippi Valley, it can readily be understood that the amount of stem-rust infection in the more northerly portion of the latter area, namely the Upper Mississippi Valley, may have a very direct influence on the amount of infection that develops in Western Canada. If allowance be made for differences in latitude, climatic conditions in the two areas are not greatly dissimilar. Moreover, the topography of the two areas is much alike. There is also a good deal of similarity in the varieties of small grains grown. As no natural barriers separate the two areas, south winds can readily carry spores from the one into the other. It would not, therefore, be surprising to find considerable agreement from year to year in the intensity of infection in the two areas.

Table 6 gives the years, from 1904 to 1938, in which stem rust was of heavy, medium, and light intensity in the Upper Mississippi Valley and Western Canada. The classification of the years from 1904 to 1925 for the former area is that given by Stakman and Lambert (207) and Lambert (113), while that of the years from 1926 to 1938 is based on reports in the *Plant Disease Reporter* and its Supplements⁸ for those years.

As shown in Table 6, there is a good deal of agreement year by year in the severity of stem rust in the Upper Mississippi Valley and in Western Canada, although some divergencies are evident. The agreement, however,

⁸ Mimeographed publications of the United States Department of Agriculture.

may be somewhat closer than represented, for in some instances it was difficult to decide whether or not a particular year should be classified more properly as a heavy rust year rather than as a medium rust year, or as a medium rust year rather than as a light rust year. Where the difficulty could not be satisfactorily resolved, the class representing the lesser rust severity was chosen. For example, in 1911 stem rust is known to have been at least rather heavy in southern and central Manitoba and prevalent in south-eastern Saskatchewan, but whether or not epidemic conditions prevailed is uncertain and hence, for Western Canada, 1911 is classed as a medium rust year rather than as a heavy rust year, although if more exact information had been available it might have been more accurately classed as a heavy rust year, and thus be brought into agreement with the classification given it in the Upper Mississippi Valley. The year 1919 could be classed with some justification as a heavy rust year, but it seems more in keeping with the actual conditions that prevailed to regard it as a medium rust year. The greatest disparity in the severity of infection in the two areas seems to have occurred in 1920, but although this year is classed as a light rust year in Western Canada, it would probably have been almost as correct to have regarded it as a medium rust year. In some other years, stem rust was somewhat heavier in one area than in the other, but probably in no year has the difference in the intensity of infection in the two areas been greater than that which could be justifiably attributed to local differences in weather conditions. The comparison, therefore, shows that during the period 1904 to 1938 there was agreement in the amount of stem rust in the two areas in 26, and apparently in more, of the 35 years, a fact that leaves little doubt that the amount of infection in the northern Mississippi Valley has a direct influence on the amount that develops in Western Canada.

TABLE 6.—CLASSIFICATION OF THE YEARS FROM 1904 TO 1938 ACCORDING TO THE INTENSITY OF STEM-RUST INFECTION IN THE UPPER MISSISSIPPI VALLEY AND WESTERN CANADA

Class of year	Upper Mississippi Valley	Western Canada
Heavy rust	1904, 1911, 1916, 1919, 1920, 1923, 1927, 1935, 1938.	1904, 1916, 1923, 1927, 1935, 1938.
Medium rust	1905, 1906, 1908, 1914, 1917, 1921, 1922, 1925, 1929, 1937.	1905, 1906, 1911, 1914, 1919, 1921, 1924*, 1925, 1930, 1937.
Light rust	1907, 1909, 1910, 1912, 1913, 1915, 1918, 1924, 1926, 1928, 1930, 1931, 1932, 1933, 1934, 1936.	1907, 1908, 1909, 1910, 1912, 1913, 1915, 1917, 1918, 1920, 1922, 1926, 1928, 1929, 1931, 1932, 1933, 1934, 1936.

* A light rust year except in Manitoba.

COMPARATIVE PREVALENCE OF PHYSIOLOGIC RACES OF WHEAT STEM RUST IN THE UNITED STATES AND CANADA

As wheat stem rust comprises a large number of different physiologic races, it would be expected that if infection in Western Canada is initiated by wind-borne spores from the south there should be an evident agreement in the identity and prevalence of at least the predominating races found in Western Canada and in the northern Mississippi Valley. Unfortunately, data for the latter area are only available for the four years discussed below, but for a few of the other years some idea of the prevalence of the different races in the two areas can be obtained by a comparison of what data are available for the United States as a whole with corresponding data for all of Canada, as the predominating races in the two areas under consideration appear to be the predominating ones in the two countries.

Stakman, Levine, and Wallace (209) made a study of the distribution and prevalence of the physiologic races of stem rust present in the Mississippi Valley in 1926, 1927, and 1928, with a view to determining whether or not such a study would provide evidence of the spread of inoculum from southern to northern States. Wallace (226) extended the study to include the whole of the United States, and with data obtained by Canadian workers made comparisons of the relative prevalence of the races of stem rust present in the United States and Canada in 1926 and 1927. (Complete data for Canada in 1928 were not available at the time that he made the comparison.) He found that, in 1926, ten of the 15 races obtained in Canada were present in the United States, the other 5 races comprising only 9 out of a total of 387 isolates. In 1927, eleven of the 19 races obtained in Canada were present in the United States. The other 8 races comprised 30 out of a total of 511 isolates. Two of these 8 races (Races 56 and 57) were obtained from infected barberry plants in the greenhouse at Winnipeg, and another (Race 53) originated at Ottawa in the vicinity of barberry. Actually, therefore, in 1927 only 5 races were found, apart from barberry, on cereals and grasses in Canada that were not found in the United States. Wallace points out that 2 or 3 races were moderately prevalent in Canada but were not found, or were found only rarely, in the United States in these years.

The comparison begun by Wallace can now be completed for 1928, and extended to include 1939, a year for which complete data are available (210). In 1928, nineteen physiologic races were found in the United States. Twelve of these races were also found in Canada, but, in addition, there were 9 others found in Canada that were not found in the United States. Six of these 9 were collected in Eastern Canada, and may have had their origin on infected barberry. In 1939, fourteen races were identified in the United States, 7 of which were found present in Canada. Nine other races were collected in Canada, although 6 of them were only isolated once.

Table 7 gives the comparative prevalence of the more commonly occurring races in the United States and in Canada during the years 1926, 1927, 1928, and 1939, and of the same races in 9 (8 in 1939) States in the Mississippi Valley—Iowa, Kansas, Minnesota, Missouri, Montana, Nebraska, North Dakota, South Dakota, Wisconsin—and in Western Canada during the same years.

TABLE 7.—PREVALENCE OF THE MORE COMMONLY OCCURRING PHYSIOLOGIC RACES OF STEM RUST IN THE UNITED STATES AND CANADA, AND IN NINE STATES OF THE MISSISSIPPI VALLEY AND IN WESTERN CANADA, IN 1926, 1927, 1928, AND 1939, EXPRESSED AS THE PERCENTAGE THAT THE ISOLATES OF EACH RACE FORMED OF THE ISOLATES OF ALL RACES IDENTIFIED IN THE RESPECTIVE YEARS AND COUNTRIES OR AREAS

Physiologic race	1926		1927		1928		1939	
	United States	Canada	United States	Canada	United States	Canada	United States	Canada
11*	17.2	3.2	7.6	0.9	6.2	1.3	3.2	1.9
14	0.9	0.5	0.7	3.5	0.0	0.5	0.1	0.6
15	0.0	0.5	0.0	1.8	0.0	5.4	0.3	0.6
17*	8.6	7.7	4.2	4.2	3.8	4.3	10.0	2.6
19	0.9	0.3	2.0	0.2	2.9	1.5	3.3	3.2
21	10.3	22.3	29.3	29.5	19.2	26.3	0.4	0.0
34	0.9	1.1	0.0	2.2	0.3	3.8	0.6	0.0
36*	56.0	55.7	37.6	45.3	30.7	39.3	0.7	0.6
38*	7.7	4.8	12.5	5.8	25.4	8.2	24.0	11.5
49	0.0	0.8	2.2	1.8	7.1	3.6	0.6	0.0
56	0.0	0.0	0.0	0.0	0.6	0.0	55.5	74.3
Total number of isolates	116	378	406	450	339	391	1063	156
	Nine States	Western Canada	Nine States	Western Canada	Nine States	Western Canada	Eight States†	Western Canada
11*	7.0	2.2	5.7	0.5	5.6	0.9	2.7	1.9
14	0.0	0.4	0.4	3.8	0.0	0.3	0.2	1.0
15	0.0	0.7	0.0	2.0	0.0	5.1	0.2	0.0
17*	1.7	7.4	4.8	4.3	4.7	4.8	12.3	1.9
19	0.0	0.4	2.2	0.0	2.3	1.6	2.9	3.9
21	10.5	22.6	31.3	30.1	24.7	29.6	0.3	0.0
34	1.7	1.1	0.0	2.3	0.5	3.5	0.5	0.0
36*	71.7	60.5	43.6	47.2	39.6	44.2	0.6	0.0
38*	1.7	0.4	6.5	3.3	12.6	2.9	19.0	9.6
49	0.0	0.7	2.6	1.8	6.5	3.5	0.5	0.0
56	0.0	0.0	0.0	0.0	0.9	0.0	60.5	76.9
Total number of isolates	57	269	229	391	219	314	625	104

* Races 11, 17, 36, and 38 differ only slightly from Races 32, 29, 18, and 39, respectively, and under some conditions are almost or wholly indistinguishable from them. For purposes of the present computation, it seems advisable to regard each pair of races (e.g. Races 11 and 32) as a single race. The percentages, therefore, given for Races 11, 17, 36, and 38 in this table include those also, respectively, of Races 32, 29, 18, and 39.

† No data given for Montana in this year.

In this table, the prevalence of a particular race in a given year is expressed as the percentage that the isolates of this race formed of the total of all the isolates obtained in that year in the respective country or area. It may be mentioned in passing that few of the isolates obtained in the United States in these years originated on infected barberry, and none of

those obtained in Canada from infected barberry are included in the table. The most arresting feature of the data is the pronounced dominance in both countries, or in both regions, of a few physiologic races, namely Races 21, 36, and 38 from 1926 to 1928, and of Races 38 and 56 in 1939. Race 38 was apparently less prevalent in the nine States and in Western Canada during the period 1926-1928 than in other parts of the two countries. In all four years, Races 11 and 17 were present in both countries, although Race 11 tended to be considerably more prevalent in the United States than in Canada, while Race 17 tended to be about as prevalent in the one as in the other. The other races were in most instances less prevalent than those just mentioned, and were more often than not present in both countries.

It is obvious that, according to Table 7, there were certain disparities in the prevalence of some of the races, at least in some years, in the two countries, and even in the Mississippi Valley and Western Canada. For example, Race 15 was not isolated in 1926, 1927, or 1928 in the United States, although it was isolated in Canada in all three years and apparently was not altogether uncommon there in the last two of these years. Similarly, Race 34 was not isolated in the United States in 1927, although, in that year, it was isolated 10 times in Canada from collections of stem rust obtained from cereals and grasses. In this connection, it may be remarked that the fact that, in one or more years, a given race was found present in Canada but not in the United States does not necessarily indicate conclusively that the race was entirely absent from the latter country. The converse is likewise true. On the other hand, the presence of Race 15 in Canada for three consecutive years and the failure in the United States to isolate this race in the same years, might indicate that the race overwintered in Western Canada. It would seem almost a mathematical certainty that Race 15 was not present in the Mississippi Valley in 1927 and 1928. Whatever may be the explanation of such anomalies, they in no way impair the strength of the positive evidence, and as adequate discussion of them would be long and probably tedious, they need be given no further consideration. The fundamental point made evident by the comparisons given in Table 7 is the pronounced similarities in the racial composition and prevalence of the rust in the areas under discussion. The fact that in each year the races predominating in the northern Mississippi Valley were the races that predominated in Western Canada, can leave little doubt as to the main source of the inoculum responsible for stem-rust outbreaks in the latter area.

For the decade following 1928, as already mentioned, detailed data relative to the prevalence of different races of stem rust in the United States are not available for comparison, except in the case of Race 56, which will be referred to presently; but Stakman and coworkers (201, 204) point out that in the United States as a whole there have been decided population drifts among physiologic races of wheat stem rust between 1930 and 1939. Similar trends in the prevalence of races of this rust have been observed in Canada (146) during these and earlier years. The data available for the United States are only illustrative and hence not extensive, but they furnish at least a limited basis for comparison. In this comparison, as in the foregoing one, the prevalence of a race in a given year is

expressed as the percentage that the isolates of the race in question formed of the total isolates of all the races found in that year in each country. The corresponding data for the two countries in the period just indicated are as follows:

—	United States	Canada
Race 21	7% in 1934, not found on wheat in 1939.	13.7% in 1934, not found on cereal or grasses in 1938 or 1939.
Race 34	0.6% in 1930, 22% in 1934, 0.6% in 1939.	7.3% in 1930 (1.3% in 1929), 19.2% in 1934, 0.0% in 1939 (1.7% in 1938).
Race 36*	36% in 1930, 0.6% in 1939.	49% in 1930, 4% in 1939.
Race 38*	Fluctuated greatly, 34% in 1930, 4% in 1934.	Fluctuated widely, 20.3% in 1930, 2.7% in 1934.
Races 17* and 19	Tended to increase slowly but irregularly.	Fluctuated considerably, but definite tendency to increase only evident in Race 17.

* See first footnote to Table 7.

From these few comparative data, it is evident that there is a parallelism between the population trends of at least certain of the more prevalent physiologic races of wheat stem rust in the two countries, although there is some disparity in the relative prevalence of individual races.

A better sequence of data is available for Race 56. In 1928, this race comprised 0.59%, and, in 1930 comprised 0.3% of all isolates made in the United States, but it was not collected on cereals or grasses in Canada until 1931, when it comprised 2.0% of all the isolates. From 1932 to 1938, the yearly prevalence of this race in the United States and Canada is indicated by the following percentages:

—	1932	1933	1934	1935	1936	1937	1938
	%	%	%	%	%	%	%
United States	2.1	3.7	33.1	44.0	47.0	57.0	66.0
Canada	7.7	5.7	28.8	50.0	61.0	53.3	69.4

The gradual increase year by year in the prevalence of this race from 1933 to 1938 in both countries is a striking feature of the rise to prominence of Race 56, and leaves little doubt that the prevalence of this race in the United States has been largely responsible for its prevalence in Canada.

Although the comparative data presented above relative to the prevalence of physiologic races of wheat stem rust in the United States and in Canada are somewhat fragmentary, the general trend of the evidence indicates that in any given year the races most prevalent in the United States are the races most prevalent in Canada, and that population trends among these races tend to correspond in the two countries. As stem rust develops earlier in the United States than in Canada, the conclusion seems justified that inoculum from the United States is introduced into Canada, the predominating races in the former providing the bulk of the inoculum and thereby becoming established as the predominating races in the latter.

RELATION OF METEOROLOGICAL FACTORS TO THE DEVELOPMENT OF STEM RUST

The influence of such meteorological factors as humidity, temperature, and light intensity on the development of stem rust has been carefully studied under controlled conditions by different investigators, and some attention has been given to wind as a means of spore dispersal. Many observations have been recorded of the relation of these factors, particularly temperature and humidity, to stem-rust development under natural conditions. In regard to this relation, it may be mentioned that it is complicated by the complex life cycle of the organism (Figure 6) and by the fact that the organism, except in the case of free spores, cannot be studied apart

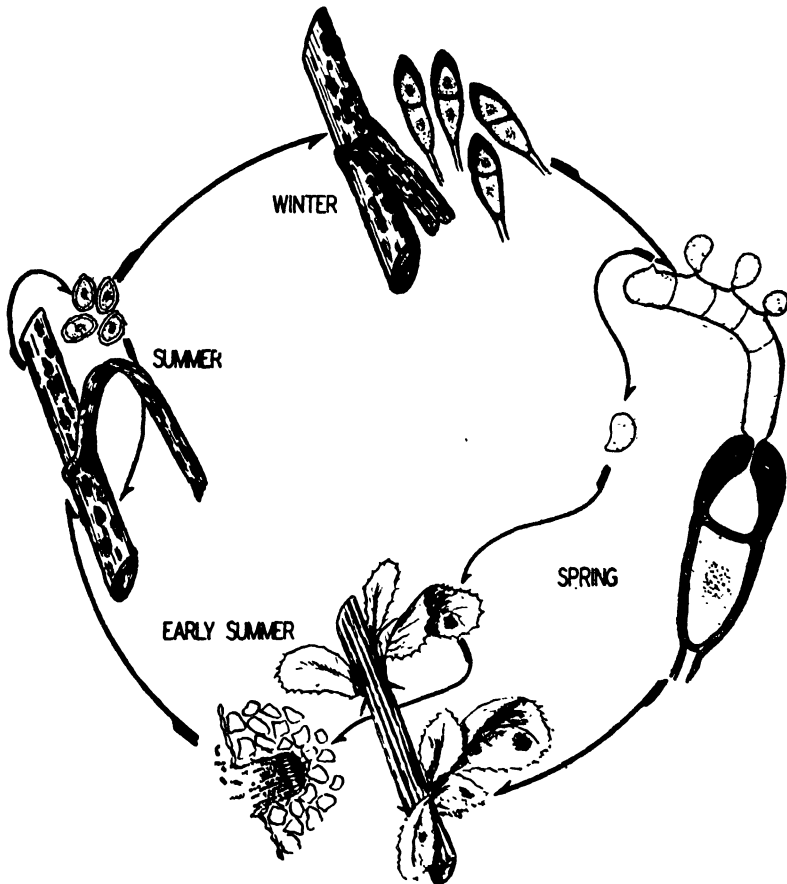


FIGURE 6. Schematic representation of the life cycle of the stem-rust fungus. The black spores (teliospores) survive the winter and germinate in the spring and early summer. Each of the 2 cells of a black spore produces a stout curved tube on which are produced 4 tiny colourless spores (sporidia), which infect common barberry. Infections on barberry produce the cluster-cup stage of the fungus. The cluster cups (aecia) produce aeciospores, and these spores infect cereals and grasses. Infections arising from them produce the red, or summer, spores. These spores (Figure 7), in turn, infect cereals and grasses; and so long as the plants remain green and weather conditions are favourable, old and new infections continue to produce urediospores, and the urediospores, new infections. When, however, the plants begin to ripen, the infections cease to produce urediospores but, in their place produce the black spores (teliospores), thus completing the life cycle of the fungus. (Drawing by Mr. W. E. Clark).

from its hosts. In the present study, however, it is only necessary to consider weather conditions in their relation to the uredial stage of the fungus, for it is with this stage (Figure 7) that the present study is almost

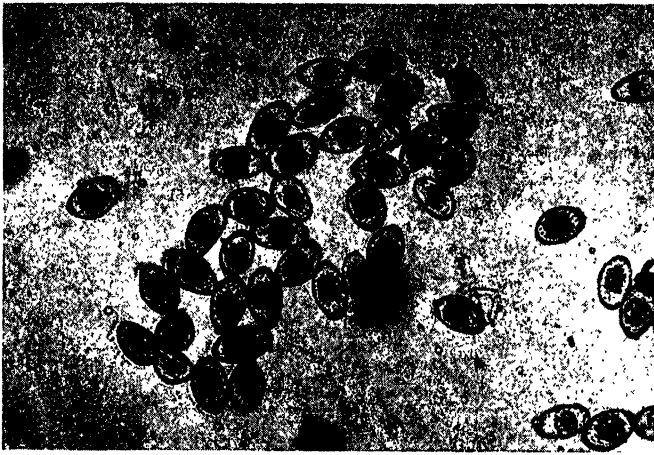


FIGURE 7. Red spores (urediospores) of stem rust. Magnification, 230 app.

entirely concerned. For a discussion of the relation of weather conditions to the other stages, and for literature citations bearing on the same, the reader is referred to Lambert (113), Zimmerman (239), and Lehmann, Kummer, and Dannenmann (117).

As earlier pointed out, there are great variations in the severity of stem-rust infection in Western Canada from year to year. In any given year, the severity is usually greatest in eastern Manitoba and decreases westward to Alberta. In order to ascertain to what extent these yearly and regional variations in rust severity are attributable to weather conditions, a study has been made of certain meteorological factors for the years 1916 to 1938, and of the relation of these factors to the development of stem rust in these years.

Because of regional differences in climatic conditions in Western Canada, the Meteorological Service of Canada recognizes a number of meteorological divisions in this area. The divisions included in this study are as follows:

- Manitoba: Red River (Eastern Manitoba).
Qu'Appelle and Assiniboine Rivers (Western Manitoba).
- Saskatchewan: Qu'Appelle River (Eastern Saskatchewan).
Saskatchewan Forks (North-central Saskatchewan).
North Saskatchewan River (North-western Saskatchewan).
South Saskatchewan River (South-western Saskatchewan).
- Alberta: North Saskatchewan River (Northern Alberta).
Red Deer River (Central Alberta).
Bow River (Southern Alberta).

These nine divisions embrace the greater part of the cultivated area of Western Canada. The two Manitoba divisions and the Qu'Appelle division in Saskatchewan comprise approximately the area most affected by stem rust. The meteorological data are presented mainly by meteoro-

logical divisions, for the reason that, if the severity of rust infection in these divisions is closely associated with seasonal weather conditions, this arrangement of the data would seem best suited to establish the association.

For purposes of this study, the years of the period just mentioned are divided (as shown in Table 6) into three classes, namely, light, medium, and heavy rust years, depending on the severity of the infection in the different years. Owing to variations in the intensity of the infection present in different meteorological divisions in individual years, these class designations relate to individual divisions rather than to Western Canada as a whole. Table 8 indicates the relative intensity of stem-rust infection in the different meteorological divisions for years in which stem-rust infection was moderate or severe in any one of the divisions. The other years of the period under discussion are regarded as light rust years in all the meteorological divisions.

The meteorological factors considered are humidity, temperature, light, and wind. In order to conserve space, data for individual years are not presented, except where imperative. For the same reason, the data relative to wind are largely restricted to the Red River division in Manitoba, where the relation of wind to stem-rust development is most clearly demonstrable. The data on light (hours of sunshine) and on relative humidity are given for certain stations, which may be regarded as representing the divisions in which they are situated. Owing to marked yearly differences, during the growing season, in the amount and frequency of rainfall in different parts of each division, and to rather wide fluctuations in temperature from day to day, and even in a single day, it is virtually impossible closely to relate such differences and fluctuations to the general development of stem rust in any given year. Perhaps the best that can be done is to determine if, in the different divisions during the period under review, the averages of the meteorological data for the medium and the heavy rust years show an appreciable deviation from those for the light rust years and for the whole period. Therefore, the data are given, wherever possible, as averages for each class of years.

TABLE 8.—SEVERITY OF STEM-RUST INFECTION ON WHEAT, BY METEOROLOGICAL DIVISIONS, IN MANITOBA, SASKATCHEWAN, AND ALBERTA IN MEDIUM AND HEAVY RUST YEARS BETWEEN 1916 AND 1938

Year	Manitoba		Saskatchewan				Alberta		
	Red River	Qu'Appelle and Assiniboine Rivers	Qu'Appelle River	Saskatchewan Forks	North Saskatchewan River	South Saskatchewan River	North Saskatchewan River	Red Deer River	Bow River
1916	H*	H	H	M	L	L	L	L	L
1919	M	M	M	M	M	L	L	L	L
1921	M	M	M	M	M	L	L	L	L
1923	H	H	H	M	L	M	L	M	M
1924	M	M	L	L	L	L	L	L	L
1925	M	M	M	M	L	L	L	L	L
1927	H	H	H	M	M	L	M	M	L
1930	M	M	M	L	L	L	L	L	L
1935	H	H	H	M	L	L	L	L	L
1937	M	M	L	L	L	L	L	L	L
1938	H	H	H	M	M	M	M	M	M

* Signification of symbols: H = Heavy infection, M = Medium infection, L = Light infection.

RELATION OF HUMIDITY TO STEM-RUST DEVELOPMENT

Spore germination and infection are the initial stages in the establishment of stem-rust infection, and these two processes cannot take place except in the presence of a sufficiency of moisture. The humidity range for germination and infection, unlike the temperature range, is very narrow indeed. Beauverie (13) states that urediospores of stem rust require to be in contact with liquid water before they will germinate. Stock (214) obtained no germination at 90, 95, or 99% relative humidity, and very little germination at 100% when no condensation water was present on the spores; but abundant germination occurred at 100% humidity when a thin film of moisture collected around them. On the other hand, Lauritzen (115) obtained some infection on inoculated plants kept at a relative humidity of 95%. Regarding this result, it may be pointed out that unless the temperature is kept constant there is the possibility that a slight temporary drop in temperature may cause the deposition of water droplets around the spores, in which case the spores may germinate not in a moist atmosphere but actually in water. As a matter of fact, in high air humidities, it is difficult to prevent such condensation droplets from forming.

The likelihood is that under field conditions stem-rust urediospores only germinate when there is liquid water present on the plants. To secure abundant infection, this condition must persist for a considerable number of hours. On seedling plants freshly inoculated and placed in moist chambers, Stakman and Levine (208) obtained the best infection on plants held in the chambers for 48 hours. Gassner and Straib (76) secured maximum infection on plants kept in moist chambers for 18 hours at a temperature of 62.6°-68° F., but recommend that the period should usually be 48 hours. Some infections, however, may occur within a much shorter period. Peltier (154) inoculated a series of seedling plants and placed them in moist chambers for different periods of time. Infection developed subsequently on 1.7% of those kept in the chambers for from 3 to 5 hours, on 17% of those kept for 6 hours, on 78% of those kept for 22 hours, and on 100% of those kept in the chambers for 36 hours. It would appear, therefore, that moisture must be present on the plants for at least a few hours to insure that infection, however slight, may be established.

Amount of Rainfall

The opinion is very widely held that wet seasons are usually seasons of heavy stem-rust infection, and this opinion is supported by numerous observations made over a long period of time. Eriksson and Henning (59) review the observations made up to 1896 and conclude from these and their own observations that the development of stem rust is favoured by abundant rainfall in July and early August, as, at that time of year in the areas under review, urediospores are most numerous and readily germinable. Sorauer (188), in 1909, enumerates some of the observations made during the preceding two decades on the relation of rainfall to stem-rust outbreaks. In general these observations indicate an association between periods of wet weather and severe attacks of stem rust. This association between wet seasons and heavy rust has been very frequently observed (9, 13, 14, 17, 25, 34, 37, 47, 143, 172, 199, 215, 222, 227). Freeman and

Johnson (67) point out that in the United States although cereal rusts are practically coextensive with their hosts, they are generally only a menace to cereal crops in areas with an annual rainfall of 20 or more inches. Levine (118) found that 90 to 100% infection of stem rust on wheat occurred at stations only where the precipitation exceeded 2.5 inches during the last two months of wheat development.

On the other hand, it is generally recognized that drenching rains tend to wash off the spores from the plants and thus limit the number of infections. According to Eriksson and Henning (59) this observation was made by Nielsen in 1874, and subsequently by Wold and by Sorauer. Bolley (23), Klebahn (111), Freeman and Johnson (67), and Stakman (189) made the same observation. Bolley points out that rain by day is of little consequence for infection unless the rain is light and the weather cloudy. Klebahn remarks that it is the humid atmosphere after rain that favours infection and that this condition can be brought about better by drizzling rain than by heavy showers. Roussakov (170) regards long continued light rain as more conducive to rust development than heavy showers, and rain at night more so than rain by day. He is of the opinion that rust development is not so much dependent on the total amount of rain as on the duration and frequency of the rains.

That rust infestation is not always severest in seasons of highest rainfall is shown by Freeman and Johnson (67) in a study of weather conditions during the 3-year period 1903-05 in the Mississippi Valley. In this area, stem-rust infection was of moderate intensity in 1903, somewhat heavier in 1905, and extremely severe in 1904. An analysis of the precipitation data showed that the year 1905 had a greater rainfall than either 1903 or 1904, whether the period studied covered the seven months or the three months prior to harvest, or the month in which the grain headed. During the three months preceding harvest, the rainfall in 1904 was below normal in all but 3 of the 10 States embraced in the study, namely, in Kansas, Missouri, and North Dakota. Furthermore, Gassner (71) relates that, in Uruguay, there is no relation between the amount of rain and the amount of stem-rust infection. Zekl (238) states that seasons of heavy infection have low precipitation but high atmospheric humidity. Lambert (113) concludes from a comprehensive study of the relation of humidity to stem-rust development in the Upper Mississippi Valley that differences in the total precipitation during May, June, and July did not seem to be associated in any way with the development of stem-rust epidemics. He remarks that "severe epidemics sometimes develop in parts of the Red River Valley in which rainfall is totally absent" while the attack is developing.

Rainfall in Western Canada. The belief is very commonly held by farmers and others in Western Canada that there is a close association between wet seasons and heavy outbreaks of stem rust. This association was mentioned by Bedford (17) in 1903 and again by Bracken (25) in connection with the 1916 epidemic. In order to determine to what extent seasonal rainfall is associated with outbreaks of stem rust, rainfall data for the nine meteorological divisions earlier mentioned have been assembled for the spring and summer months from 1916 to 1938, and are presented in Tables 9, 10, and 11. The data for the months of April and May are

combined in Table 11, as the rainfall of these two months does not directly influence the development of stem rust, the disease being not then present. The amount of rainfall in these two months, however, influences crop growth and thus indirectly stem-rust development.

Table 9 gives the means of the rainfall for the 5-month period April to August and for the 3-month period June to August in the nine meteorological divisions earlier mentioned. This table shows that in each of the divisions the average rainfall for the 5-month period, as well as for the 3-month period, is greater both in the medium and in the heavy rust years than in the light rust years, and hence the respective means for the whole period of years occupy in each division an intermediate position between the medium and heavy rust years and the light rust years. There is, therefore, a distinct tendency in Western Canada for years of medium or heavy rust infection to be associated with years of above-average spring and summer rainfall.

TABLE 9.—MEAN RAINFALL IN MANITOBA, SASKATCHEWAN, AND ALBERTA, BY METEOROLOGICAL DIVISIONS, FOR THE 5-MONTH PERIOD APRIL TO AUGUST AND FOR THE 3-MONTH PERIOD JUNE TO AUGUST, FROM 1916 TO 1938, FOR YEARS IN WHICH STEM RUST WAS LIGHT, MEDIUM, AND HEAVY IN THE DIVISIONS INDICATED

Meteorological Divisions	Months	Rainfall*			
		Light	Medium	Heavy	23-year period
		in.	in.	in.	in.
<i>Manitoba</i>					
Red River	April – August	9.13	12.52	11.33	10.49
	June – August	6.75	8.68	7.61	7.44
Qu'Appelle and Assiniboine Rivers	April – August	9.61	11.17	13.18	10.80
	June – August	7.11	7.51	9.75	7.79
<i>Saskatchewan</i>					
Qu'Appelle River	April – August	8.07	9.84	11.76	9.18
	June – August	5.77	7.39	8.64	6.67
Saskatchewan Forks	April – August	7.82	10.86	—	8.88
	June – August	5.72	8.11	—	6.54
South Saskatchewan River	April – August	7.63	9.80	—	7.81
	June – August	5.73	7.22	—	5.85
North Saskatchewan River	April – August	8.40	9.60	—	8.61
	June – August	6.30	6.46	—	6.33
<i>Alberta</i>					
Bow River	April – August	8.78	12.20	—	9.08
	June – August	5.61	7.75	—	5.79
Red Deer River	April – August	9.87	12.97	—	10.27
	June – August	6.86	9.18	—	7.12
North Saskatchewan River	April – August	10.13	11.00	—	10.21
	June – August	7.36	7.97	—	7.45

* Amount of rainfall expressed in inches.

On the other hand, it should be pointed out that all heavy rust years were not wet years, or conversely, all wet years, heavy rust years. This fact is evident from Table 10, which gives departures from the normal in the amount of rainfall during the 5-month period April to August and the 3-month period June to August in certain years for five meteorological divisions of Western Canada. The years for which data are given comprise

TABLE 10.—DEPARTURES FROM THE NORMAL IN THE AMOUNT OF RAINFALL FROM APRIL TO AUGUST AND FROM JUNE TO AUGUST IN CERTAIN YEARS BETWEEN 1916 AND 1938 IN FIVE METEOROLOGICAL DIVISIONS OF WESTERN CANADA:
MEDIUM AND HEAVY RUST YEARS IN WHICH THE RAINFALL WAS
BELOW NORMAL, AND LIGHT RUST YEARS IN WHICH
THE RAINFALL WAS ABOVE NORMAL

Meteorological Divisions	Medium and heavy rust years			Light rust years		
	Year	Apr.-Aug. in.*	June-Aug. in.	Year	Apr.-Aug. in.	June-Aug. in.
Red River	1916	- 0.24	—	1918	+ 0.51	+ 0.91
	1923	- 2.30	- 1.29	1922	+ 1.31	+ 0.26
	1925	- 0.29	—	1926	—	+ 0.91
	1938	- 1.04	- 1.09	1928	+ 4.96	+ 5.36
Qu'Appelle and Assiniboine Rivers	1919	—	- 0.34	1922	+ 0.70	+ 0.76
	1921	- 0.45	- 1.14	1926	—	+ 0.56
	1924	—	- 0.29	1928	+ 1.20	+ 1.81
	1925	- 0.75	—	1931	—	+ 0.46
	1930	- 0.15	- 0.74	1932	+ 0.70	+ 1.31
	1938	- 2.60	- 1.74	1936	+ 2.35	+ 0.86
Qu'Appelle River	1919	- 0.33	- 0.16	1922	+ 0.70	—
	1925	- 0.53	—	1926	—	+ 0.56
	1930	- 1.78	- 1.37	1928	+ 1.20	+ 1.81
	1938	- 0.93	- 0.64	1931	—	+ 0.46
				1932	+ 0.70	+ 1.31
South Saskatchewan River (Sask.)				1936	+ 2.35	+ 0.86
	1938	- 0.26	- 1.25	1916	+ 6.54	+ 5.65
				1920	+ 0.84	—
				1921	+ 0.84	—
				1922	+ 1.74	+ 1.00
				1924	+ 0.34	+ 0.20
				1925	+ 1.09	—
				1927	+ 5.49	+ 0.75
				1928	+ 1.09	+ 1.85
				1930	—	+ 0.75
				1932	+ 3.24	+ 2.30
				1933	+ 1.19	—
				1935	+ 1.64	—
North Saskatchewan River (Alta.)	1938	- 0.90	- 0.17	1916	+ 3.89	+ 3.35
				1921	+ 0.44	+ 0.25
				1923	+ 3.34	+ 3.65
				1924	+ 0.89	+ 0.90
				1928	—	+ 0.65
				1930	+ 1.09	+ 1.20
				1931	+ 1.39	+ 2.80
				1932	+ 0.44	—
				1935	+ 1.99	+ 1.00
				1937	+ 0.59	+ 0.80

* Departures from normal in amount of rainfall expressed in inches.

TABLE 11.—MEAN MONTHLY RAINFALL IN MANITOBA, SASKATCHEWAN, AND ALBERTA, BY METEOROLOGICAL DIVISIONS, FOR THE MONTHS OF APRIL, MAY, JUNE, JULY, AND AUGUST FROM 1916 TO 1938, FOR YEARS IN WHICH STEM RUST WAS LIGHT, MEDIUM, AND HEAVY IN THE DIVISIONS INDICATED

Meteorological Divisions	April-May			June			July			August		
	Light	Medium	Heavy	Light	Medium	Heavy	Light	Medium	Heavy	Light	Medium	Heavy
	in.*	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
<i>Manitoba</i>												
Red River	2.30	3.84	3.72	2.70	3.23	2.73	2.28	3.59	2.52	1.78	1.86	2.36
Qu'Appelle and Assiniboine Rivers	2.50	3.66	3.44	2.65	3.28	3.69	2.29	2.40	3.47	2.17	1.83	2.58
<i>Saskatchewan</i>												
Qu'Appelle River	2.30	2.50	3.12	2.43	3.89	3.65	1.62	2.16	3.21	1.71	1.29	1.78
Saskatchewan Forks	2.04	2.71	—	2.49	3.02	—	1.69	2.95	—	1.60	1.82	—
South Saskatchewan River	2.43	2.57	—	2.37	3.90	—	1.81	2.17	—	1.49	1.15	—
North Saskatchewan River	2.10	3.14	—	2.62	1.75	—	1.91	2.85	—	1.77	1.86	—
<i>Alberta</i>												
Bow River	3.18	4.45	—	2.41	3.95	—	1.64	2.27	—	1.54	1.52	—
Red Deer River	3.55	3.78	—	2.48	3.25	—	2.25	3.33	—	2.07	2.90	—
North Saskatchewan River	2.77	3.02	—	2.59	2.45	—	2.60	3.17	—	2.15	2.30	—

* Amount of rainfall expressed in inches.

those medium rust years and those heavy rust years in which the rainfall for the periods indicated was below normal, and those light rust years in which the rainfall for the same periods was above normal. The first three of the divisions for which data are given embrace most of the bad rust area; the other two may be regarded as representing the area relatively free in most years from stem-rust attacks. Table 10 shows that in the Red River division the rainfall for the two periods was definitely below normal in 2 (1923 and 1938) of the 5 epidemic years, and slightly below normal for 1 period (April to August) in 1 other epidemic year (1916) and in 1 medium rust year (1925). In the same division, the rainfall was above normal for the April to June period in 3, and for the June to August period in 4 light rust years. In the second division (Qu'Appelle and Assiniboine Rivers), there was less than normal rainfall for at least one of the periods in 5 medium rust years and in 1 heavy rust year, while there was above-average rainfall for at least one of the periods in 6 light rust years. In the Qu'Appelle River division, 3 medium rust years and 1 heavy rust year had less than normal rainfall in at least one of the periods, whereas 6 light rust years had above-average rainfall.

In the two more westerly divisions (South Saskatchewan River in Saskatchewan and North Saskatchewan River in Alberta), the rainfall in a considerable number of the light rust years was above normal for at least one of the periods. Some of these years are classed as heavy rust years (e.g. 1916, 1923, 1927, and 1935) or as medium rust years (e.g. 1921, 1925, and 1930) in the first three divisions. Attention may be called to the excessive rainfall in both of these westerly divisions in 1916, and in one of them in 1927 and in the other in 1923. The failure of stem rust to reach epidemic proportions in these three years in the westerly divisions of Western Canada was certainly not due to lack of rainfall. If it had been, the Red River division (Manitoba) would be expected to have been comparatively free of stem rust in 1916, for in that year the rainfall in the South Saskatchewan division and in the North Saskatchewan division (Alberta) was, respectively, for the 5-month period 14.35 and 14.10 inches, and for the 3-month period, 11.45 and 10.75 inches, whereas, in the Red River division, where severe infection developed, the rainfall for the 5-month period was 10.25 and for the 3-month period 7.55 inches. Furthermore, stem rust was of medium or severe intensity in 1938 in all of the meteorological divisions, but the rainfall was below normal for both periods in all divisions. Conversely, in 1928, rainfall was above normal for the June to August period and for the April to August period in all divisions excepting the North Saskatchewan division of Saskatchewan, and of Alberta. In some of the divisions, the excess over the normal rainfall was very pronounced in that year, as, for instance, in the Red River division in Manitoba. In spite of the exceptional rainfall, the amount of stem-rust infection was small, in fact about the smallest in any of the years under review. It would appear, therefore, that although an association between years of heavy seasonal rainfall and years of medium and of heavy stem-rust infection does undoubtedly exist in Western Canada, the association is not necessarily a close one and it seems to be dependent on some other factor or factors, chiefly, perhaps, on the abundance of inoculum.

This conclusion is supported by the fact that in 1938 rainfall was below normal in western Saskatchewan and in Alberta, yet stem rust was of medium severity in both these areas. In that year, according to Stakman (197), heavy infection extended unusually far westward in the Mississippi Valley, into Colorado, Wyoming, and Montana. It would seem, therefore, that the widespread occurrence of moderately heavy infection in western Saskatchewan and in Alberta in a comparatively dry year was in no small measure attributable to the introduction of an abundance of inoculum, which introduction was made possible by the unusually far westward extension of heavy stem-rust infection in States to the south and southeast of these two areas. This point will be mentioned again in connection with the discussion of winds favourable to the introduction of spores into different parts of Western Canada.

To ascertain if the higher average rainfall of the medium and the heavy rust years is due to an increased rainfall in any particular month, the rainfall data for the spring and summer months are summarized by months in Table 11 for the same meteorological divisions. In this table, it is seen that the excess of rainfall in the medium and the heavy rust years over the rainfall of the light rust years is spread over the five months. That is to say, the excess is not accounted for by exceptionally heavy rain in some particular month. The average rainfall in April to May and in July in all divisions is higher in the medium and the heavy rust years than in the light rust years; whereas, the average rainfall in June in two divisions, and the average rainfall in August in three divisions, is slightly less in the medium rust years than in the light rust years. It would appear, therefore, that in the medium and the heavy rust years the April to May and the July rainfall was more consistently above average than was the June or the August rainfall.

Frequency of Rainfall

Such terms as damp, humid, moist, rainy, and wet, are commonly used in the literature to describe weather conditions associated with severe outbreaks of stem rust, and there is little doubt that in most cases they imply the frequent occurrence of rain in greater or less amount and of varying duration. Roussakov (170) expresses the opinion that stem-rust development is not so much dependent on the total amount of rainfall as on the duration and frequency of rain, but Klebahn (111) believes that a very high frequency of rain, like heavy rainfall, does not provide the best conditions for the spread of the disease. Tehon and Young (215) show that in Illinois the severe outbreak of stem rust in 1923 was preceded by more than a week of rainy days, and that frequent rains fell during the period in which the disease was becoming established. Peltier (157) states that in most years in Nebraska the lack of an even distribution of sufficient precipitation after primary infection occurs is the major limiting factor in the development of subsequent uredial generations. Tiemann (218) relates that in Silesia heavy showers at intervals occurred during June and July while the heavy attack of 1932 was in process of development. In his study of stem-rust outbreaks in the Upper Mississippi Valley, Lambert (113) finds that during the 22-year period 1904-1925 there was no evident association between years of severe infection and years with a high number of days on which rain in measurable amounts fell.

In the present study, the relation between the occurrence of heavy outbreaks of stem rust and the number of days with rain during the growing season was given consideration. The relevant data are summarized in Tables 12 and 13. Table 12 shows that the average number of days with 0.01 or more inches of rain during the 3-month period June to August in the first three meteorological divisions was upwards of 4 or more days higher in the heavy rust years than in the light rust years, and, in all the divisions, the number is higher in the medium rust years than in the light rust years, although in two divisions the difference is very slight. Table 13 shows that the days with rain are more or less evenly distributed through the three months and that there is a tendency in each of the three months for the heavy rust and the medium rust years to have more rainy days than the light rust years. In two of the divisions, however, the number of days with rain in June is less in the medium rust years than in the light rust years, and less also in August in one of these divisions. It is evident, therefore, that in Western Canada years with a high number of rainy days during the growing season tend to be associated with years of medium or heavy stem-rust infection.

TABLE 12.—MEAN NUMBER OF DAYS WITH 0.01 OR MORE INCHES OF RAIN IN MANITOBA, SASKATCHEWAN, AND ALBERTA, BY METEOROLOGICAL DIVISIONS, FOR THE 3-MONTH PERIOD JUNE TO AUGUST, FROM 1916 TO 1938, FOR YEARS IN WHICH STEM RUST WAS LIGHT, MEDIUM, AND HEAVY IN THE DIVISIONS INDICATED

Meteorological Divisions	Light	Medium	Heavy	23-year period
	days	days	days	days
<i>Manitoba</i>				
Red River	22.0	24.3	26.2	23.5
Qu'Appelle and Assiniboine Rivers	24.7	25.0	29.0	25.7
<i>Saskatchewan</i>				
Qu'Appelle River	22.8	23.2	26.6	23.6
Saskatchewan Forks	25.7	30.0	—	27.1
South Saskatchewan River	20.4	26.0	—	20.9
North Saskatchewan River	24.3	24.7	—	24.4
<i>Alberta</i>				
Bow River	21.0	30.5	—	21.9
Red Deer River	28.3	32.0	—	29.0
North Saskatchewan River	27.9	28.5	—	28.0

The association, however, seems not to be a close one. For example, in the Red River division, the number of days with rain was below normal in 2 heavy rust years (1916 and 1923) and in 2 medium rust years (1919 and 1930), while in 4 light years (1922, 1928, 1932, and 1934) the number was above normal. In the other Manitoba divisions (Qu'Appelle and Assiniboine Rivers), 4 medium rust years had less than the normal number of days with rain and 5 light rust years had more than the normal number. In the other division, the number of light rust years with an above-average number of days with rain increased progressively westward, the Red Deer River and the Bow River divisions having each 11 years with more than the average number of rainy days. What significance a higher-than-normal frequency of days with rain during the growing season may have

on stem-rust development, would appear to depend on circumstances. It is probable that the timeliness of rain in relation to the occurrence of spore showers would be of more significance than the actual number of rainy days in a season. There is, of course, as a matter of chance, a greater probability of timeliness of rain when the days of rain are above average than when they are below average. The timeliness of rains with respect to the occurrence of spore showers will be considered further in connection with the discussion on the interrelation of factors influencing the development and spread of stem rust.

TABLE 13.—MEAN NUMBER OF DAYS WITH 0.01 OR MORE INCHES OF RAIN IN MANITOBA, SASKATCHEWAN, AND ALBERTA, BY METEOROLOGICAL DIVISIONS, FOR THE MONTHS OF JUNE, JULY, AND AUGUST, FROM 1916 TO 1938, FOR YEARS IN WHICH STEM RUST WAS LIGHT, MEDIUM, AND HEAVY IN THE DIVISIONS INDICATED

Meteorological Division	June			July			August		
	Light	Medium	Heavy	Light	Medium	Heavy	Light	Medium	Heavy
	days	days	days	days	days	days	days	days	days
<i>Manitoba</i>									
Red River	8.2	9.5	8.8	7.1	7.5	9.4	6.7	7.3	8.0
Qu'Appelle and Assiniboine Rivers	9.1	9.8	10.2	7.9	7.6	10.4	7.7	9.1	8.4
<i>Saskatchewan</i>									
Qu'Appelle River	8.7	9.7	10.2	6.9	7.2	9.2	7.2	6.2	7.2
Saskatchewan Forks	9.4	10.8	—	7.8	10.6	—	7.8	8.5	—
South Saskatchewan River	8.4	10.0	—	6.4	9.0	—	5.6	7.0	—
North Saskatchewan River	9.6	7.5	—	7.6	10.0	—	7.3	7.2	—
<i>Alberta</i>									
Bow River	8.2	12.0	—	6.1	10.5	—	6.6	8.0	—
Red Deer River	10.3	10.0	—	8.7	12.0	—	9.3	10.0	—
North Saskatchewan River	9.6	8.5	—	9.5	10.5	—	8.7	9.5	—

Occurrence of Mist and Fog

Wherever mist or fog is of frequent occurrence in grain-growing areas, both are undoubtedly important factors in promoting stem-rust infection. Klebahn (111) emphasizes the rôle played by fog, and Freeman and Johnson (67) assert that misty weather is particularly favourable for infection. Misty or foggy weather, although it would promote infection, would not, however, provide suitable conditions for the development of the organism within the plant tissues, as such weather is usually cool and dull, whereas warmth and sunshine, as mentioned elsewhere in this paper, are needed by the fungus to stimulate growth and spore production. If inoculum is present, a day or two of misty or foggy weather followed by bright warm days would favour stem-rust development.

Mists and fogs rarely occur in Western Canada during the growing seasons. For the years under review, records of the occurrence of mist seem to be entirely wanting, and to a large extent the same may be said of fog in all but a few districts where the local topography favours its

formation. From 1916 to 1923, fog was of more frequent occurrence at Minnedosa, Manitoba, than at any other point in the grain-growing area, but the average number of days on which it occurred from June 15 to July 30 was 4 for the light and the medium rust years and 3 for the heavy rust years. During these 13 years, fog is rarely recorded at any other station in the cultivated area of Manitoba. For example, at Winnipeg, it was reported only on July 10, 1916, and on July 6 and 16, 1917. At a few stations in Saskatchewan, such as Battleford, Swift Current and Qu'Appelle, the average occurrence is 1 or less than 1 each year. After 1928, the dates on which fog occurred are not given in the meteorological reports, so that the dates of its occurrence in June and July are not known; but at Minnedosa it was not reported during these two months in any year more than 3 times and the average occurrence for the ten years is 1 per year. The highest average for any of the Saskatchewan stations is slightly less than that for Minnedosa. It would appear, therefore, that in Western Canada fog is a factor of little consequence in the promotion of stem-rust epidemics, although if viable inoculum is present where and when it occurs, it undoubtedly presents favourable conditions for infection.

Relative Humidity of the Air

Owing to the dependence of stem rust on the presence of moisture to facilitate the germination of spores and the infection of plants; it might be regarded as a logical deduction that seasons of high atmospheric relative humidity would be associated with seasons of severe outbreaks of the disease. In this connection, it would be well to distinguish between moisture present in the air as rain, mist, or fog, and moisture present as water vapour. The relative humidity of the air at any given time represents the capacity of the air to hold water in the form of vapour, and is expressed as a percentage of this capacity. It varies from day to day, and even from hour to hour, depending on the amount of water vapour present and the air temperature. If the actual amount of water vapour present in the air remains unchanged, the relative humidity falls as the temperature rises, and rises as the temperature falls. A greater or less amount of water vapour is always present in the air and it is the source of all precipitated moisture. If fog or mist is present or rain is falling, the relative humidity is high, the air being at or nearly 100% saturation. When the relative humidity and the temperature are both high, the weather is sultry and feels oppressive.

In the different studies that have been made on the relation of weather conditions to the development of stem rust, only a few give consideration to the relative humidity of the air, a fact which may mean that the relative humidity of the air—as distinct from the occurrence of precipitated moisture—during the development period of the disease, is of comparatively minor importance. Freeman and Johnson (67) show, in a comparison of the relative humidity in the Mississippi Valley during the month containing the critical period for stem rust in the several States of that area, that the relative humidity in 1903 was about normal, in 1904 about 1.6% above normal, and in 1905 approximately 6.0% above normal. Stem rust was extremely severe in 1904, but although very prevalent in 1905 was considerably less destructive than in 1904. In 1903 it was of moderate

intensity. If the intensity of infection bore a direct relationship to the height of the relative humidity, infection should have been least in 1903, which it was, and greater in 1905 than in 1904, which it was not. According to Gassner (71), the prevalence of stem rust in Uruguay is not associated with high relative humidity, as the humidity is highest in winter when the rust is least evident or absent. He points out, however, that in summer, owing to the lower temperatures at night, the relative humidity in the early morning reaches or almost reaches the saturation point every day, thus favouring spore germination and infection. Lambert (113) is inclined to the belief that the high relative humidity of the morning air in the Red River Valley in Minnesota is correlated with the occurrence of dew, a factor which he regards of much importance in the promotion of stem-rust attacks. Tiemann (218) states that in the vicinity of Breslau, Germany, in 1932, wheat became heavily rusted in July, and that for this month the relative humidity averaged 88%, an excess over that of the two previous years of 10 to 12%. Zekl (238) claims that epidemics of stem rust occur in seasons of low precipitation and high atmospheric humidity.

To ascertain if high relative humidity during the growing season is characteristic of heavy rust years in Western Canada, an examination has been made of data for several stations in this area for the 23-year period under review. Table 14 presents the general means of the average daily relative humidity for June, July, and August at Winnipeg and Minnedosa in Manitoba, at Qu'Appelle, Saskatoon, and Swift Current in Saskatchewan, and at Medicine Hat and Edmonton in Alberta, for light, medium, and heavy rust years.

TABLE 14.—MEAN RELATIVE HUMIDITY FOR THE MONTHS OF JUNE, JULY, AND AUGUST, FROM 1916 TO 1938, AT THE SEVEN STATIONS INDICATED, FOR YEARS IN WHICH STEM RUST WAS LIGHT, MEDIUM, AND HEAVY IN THE METEOROLOGICAL DIVISIONS REPRESENTED BY THE STATIONS

Station	June			July			August		
	Light	Medium	Heavy	Light	Medium	Heavy	Light	Medium	Heavy
Winnipeg	67.3	70.6	65.2	69.9	70.6	68.8	71.3	73.0	67.0
Minnedosa	73.2	76.6	74.4	72.0	76.0	79.0	76.0	77.3	77.2
Qu'Appelle	69.0	68.8	69.6	69.2	67.0	75.0	69.9	66.6	73.0
Saskatoon	62.7	64.8	—	60.7	66.4	—	64.7	69.1	—
Swift Current	62.7	71.5	—	60.4	66.0	—	61.3	66.0	—
Medicine Hat	61.6	66.5	—	56.8	63.0	—	59.7	64.0	—
Edmonton	62.4	65.0	—	66.3	70.0	—	68.7	71.0	—

The data show that the relative humidity is slightly higher at Winnipeg, but slightly lower at Minnedosa and Qu'Appelle for each of the three months in the light rust years than in the heavy rust years. At all of the stations, except Qu'Appelle, the medium rust years have a higher average relative humidity in these months than have the light rust years. On the other hand, the relative humidity is higher, except in two or three instances, in each month at Winnipeg, Minnedosa, and Qu'Appelle in the light rust years than at the other stations in the medium rust years. There seems, however, to be a slight tendency in Western Canada for seasons in which

stem-rust infection was light to have a somewhat lower average relative humidity than seasons in which infection was more pronounced. The tendency seems more evident in the more westerly parts of this area. As the differences between the average percentages of relative humidity in the light rust class of years and those in the other two classes are small in most instances, it is doubtful if the differences have had any appreciable effect on the amount of stem rust that developed. It will be seen later that the average temperatures for the respective months varied but slightly from the normal in any of the three classes of years. Perhaps, therefore, at those stations, or rather in the divisions represented by them, where there was an appreciable increase in the relative humidity during seasons of medium or severe rust infection, dews might have been slightly more frequent, or at least more copious, than normal, and, therefore, conditions for infection more favourable. The data for Winnipeg, however, show that epidemics may develop in the Red River division in seasons when the average relative humidity is slightly below that for non-epidemic seasons. The average relative humidity in the light rust years at this station is, however, somewhat higher each month than in the same years at the four most westerly stations, but it is not probable that at these stations the relative humidity of the air has been a limiting factor in stem-rust development.

Frequency of Dew

The frequent occurrence of copious dews at night during the summer months is very widely regarded as providing favourable conditions for spore germination and plant infection. For these processes, dew is obviously a better medium than rain, for dew collects gradually, wetting the plant surface uniformly, and is less likely than rain to wash off spores from the plants. Eriksson and Henning (59) and Sorauer (188) refer to a few early reports in which the occurrence of abundant dew is said to have promoted heavy rust infection, and they mention many instances in which hot sunny days followed by cool nights during summer are said to have provided conditions favourable to rust. The latter weather conditions should probably be interpreted to mean that during such periods the deposition of dew at night was abundant, although undoubtedly the warm day temperatures also had a favouring effect. Bolley (23), Klebahn (111), Freeman and Johnson (67), Roussakov (170) and some others (9, 24, 42, 71, 106, 118, 218) have emphasized the importance of heavy dews in promoting rust infection. Lambert (113) states that in some years heavy stem rust developed in parts of the Red River Valley during periods when rain was entirely absent, and he suggests that this was made possible by abundant dew formation during such periods.

Although no official records are available relative to the frequency or abundance of dew formation in Western Canada, it is a well known fact that in this region, owing to the rapid radiation that occurs at night, dews are both frequent and abundant during the summer months. To gain some idea of the approximate number of nights on which dew forms in early summer, a computation was made involving the daily temperature and relative humidity at 7.00 p.m. and the minimum temperature at night, at Winnipeg, for each day of the last two weeks of June and the first week

of July over a period of twelve consecutive years. By reference to Table 42 of the Smithsonian Meteorological Tables (Revised Addition, Washington, 1896), it was determined from these data for each day whether or not the relative humidity at 7.00 p.m. and the fall in temperature after 7.00 p.m. were sufficiently great to reduce the water-holding capacity of the air to the dew point. The relative humidity data apply to the air at a point 4 feet above ground level. As the data are only indicative, and, as their presentation would be cumbersome, they are omitted here, although those for three or four years are included subsequently in Table 26. It was found that the temperature-humidity relation was such as to indicate that, at 4 feet above ground, the air reached the dew points on from 65 to 70% of the nights during those three weeks.

On some of the nights for which dew formation is indicated, the wind velocity was too great to permit the deposition of dew, but how frequently this happened is not known, as the wind often abates considerably after sunset, and hence its velocity at 7.00 p.m. is not a very accurate index of its velocity between midnight and early morning. The number of nights, however, on which wind prevented the formation of dew in the period discussed was probably comparatively small in any particular year. On the other hand, the humidity of air within the standing crops during periods of dry weather is probably appreciably higher than that of the surrounding air, as there is considerable loss of moisture from the soil as well as from the plants themselves, and as the air amongst the plants is less subject than the air outside to disturbance by wind. Roussakov (171) found that during night in dry summers in the south-eastern Russian steppes the relative humidity in the midst of crops at a point about 4 inches above ground level is from 15 to 50% higher than that outside them at a level approximately 4 feet above ground; although, during daytime and in wet seasons, the data did not warrant the drawing of conclusions. In dry weather, the air about the upper half of the plants would probably, therefore, have a higher humidity than that outside them, and as it is from these parts that radiation is most pronounced, dew was probably present on them on some nights in which dew formation was not indicated by the humidity and temperature data.

At any rate, the deposition of dew on the plants at night is of very frequent occurrence during the summer in Western Canada. If the crops are thick and rank, as they usually are in bad rust years, dew droplets frequently persist on the more sheltered parts of the plants throughout the morning until well on toward noon. There can be little doubt that stem-rust infection in Western Canada is very definitely facilitated by the occurrence of frequent dews.

RELATION OF TEMPERATURE TO STEM-RUST DEVELOPMENT

The cardinal temperatures for development of the uredial, or summer, stage of stem rust have been determined under controlled conditions. Johnson (103) found that, for urediospore germination, the minimum and maximum temperatures were near 35° and 88° F., respectively, and the optimum range between 53° and 63° F. His results are in general agreement with those of Mehta (130), Stock (214), and Wilhelm (236), although these investigators, and others (36, 137, 237) found the upper limit of the

optimum range to be slightly higher, about 68° F. Sibia (184) states that exposure of urediospores to a temperature of from 95° to 99° F. completely inhibited germination. Hwang (97) found, however, that urediospores of Race 36 of stem rust could withstand very well a temperature of 111° F. for 48 hours, but that, at 122° F., they lost vitality rapidly and all were dead within 60 hours. At 140° F., more than one-half of the spores lost their vitality in 4 hours, and none were viable after 15 hours.

For infection and the subsequent development of the organism within the host, the optimum temperature is somewhat higher than for spore germination. Stakman and Levine (208) found the best rust development between 66.5° and 70° F., while Peltier (151) found it to be somewhat higher, between 68° and 77° F., and Gassner and Straib (76), slightly lower, between 62.6° and 68° F. Mattras (124) found the optimum range to be wider, between 64.4° and 77° F., and this range corresponds closely with that at which Johnson and Newton (104) obtained best development. Vigorous stem-rust development may, therefore, be expected to take place at temperatures between 65° and 75° F.

Temperatures above or below the optimum tend to retard stem-rust development. Lauritzen (115) obtained slight infection at 45.5° F. but none at 42° F. (one experiment only). Peltier (151) states that development was practically suspended when the temperature fell to 50° F. or rose to 86° F. He observed no development at 41° F. after a period of 9 weeks. Mehta (130), however, records limited spore formation at 40° F. after 3 weeks; but, after the same lapse of time, Gassner and Straib (76) observed no evidence of development at temperatures between 46.4° and 57.2° F. They found the stem-rust fungus to be relatively resistant to the protracted action of high temperatures (86° to 95° F.), a finding supported by Johnson and Newton (104), who obtained rust development on wheat and oats at temperatures between 95° and 99° F. At these temperatures, however, development was noticeably less vigorous than at somewhat lower temperatures. Stakman and Levine (208) observed a retardation in the incubation period of 1 day for every rise in temperature of 10 degrees above 70° F. and of 1 day for every fall of 5 degrees below 66.5° F. A somewhat more pronounced retardation in rate of growth was found by Melander (137) in Race 35, which, at 68° F., produced spores normally within 10 or 11 days, but, at 50° F., within 18 days.

Although stem-rust development may become largely suspended at extreme temperatures, say, at a low of 40° F. and a high of 100° F., the organism in the host plant is not killed by these temperatures, and can resume development when temperatures become less extreme. Indeed the organism can survive much lower temperatures and considerably higher ones. Melander (137) found that the mycelium of wheat stem rust was capable of growth after storage for 80 days at temperatures just at and above the freezing point. As a matter of fact, he showed that, at this temperature, urediospore production was quite possible, although some races were better able than others to develop under such conditions. From his results, he concludes that the organism in the host tissue can withstand as low a temperature as the host plant can endure, thus confirming the earlier findings of Stakman and Levine (208). Apparently, too, the organism can survive about as high a temperature as can be tolerated by

the host. In one experiment, Stakman and Levine (208) subjected newly infected plants during the incubation period to a maximum daily temperature of 103.5° F. and a minimum daily mean of 71.1° F. and obtained a moderate degree of infection. Johnson and Newton (104) record that, in 1936, between June 27 and July 15, the temperature in the greenhouse rose as high as 116° F., the mean daily maximum being 99.6° F. and the mean daily minimum 66.8° F. Infection developed in wheat seedlings inoculated on June 27, and, although in some races of the rust, the infection types were abnormal, other races (e.g., Race 48), seemed uninfluenced by such temperatures. At a uniform temperature of 95° to 99° F., moderately good development occurred in some races but not in others. Both host and organism showed evidence of decreasing vigour at these temperatures. Cassell (36) showed that Race 15 could survive an average temperature of 105° F., with a maximum of 131° F., for 14 days.

A comparison of the optimum temperatures for the growth of the cereal host with the optimum for stem-rust development brings out an interesting relationship. It has just been seen that the optimum temperature for spore germination lies approximately between 55° and 65° F., and for stem-rust development, between 65° and 75° F. A temperature between 60° and 70° F. may, therefore, be regarded as well suited to stem rust. It was found by Peltier (151) that for eight different varieties of wheat, the best growth occurred between 59° and 68° F., and by Hutcheson and Quantz (96), that, for one variety each of wheat, oats, barley, and rye the best development occurred at 62°, 65° to 75°, 58° to 62°, and 62° F., respectively. Although the optimum temperature for cereals may vary somewhat with the species or with the variety, it may be said, in general, that the range of temperature that permits good development of the parasite also permits good growth of the hosts. Temperatures below or above the optima tend to retard, and, if the departure is sufficiently great, even inhibit growth both of the organism and of the hosts.

It would appear from the observations and studies of many different investigators that hot weather is generally associated with severe outbreaks of stem rust in the Mississippi Valley. Walster (227), in a comparison of five epidemic and five non-epidemic years, showed that during the growing season maximum temperatures rose more rapidly and reached their highest point sooner in epidemic years than in non-epidemic years. Tehon and Young (215) considered that in Illinois a mean temperature of 71.5° F. (accompanied by high humidity) was optimum for field infection. For the period 1919 to 1923, Levine (118) found a definite correlation between the mean temperature of the last two months of the growing season (July and August in Western Canada) and the severity of stem rust. The correlation coefficient, however, was rather low ($+ 0.283 \pm 0.038$). No infection developed at stations where the mean temperature was below 60° F., but heavy infection developed at stations where the mean temperature was comparatively high (ranging from 66° to 72° F.). Waldron (224, 225) points out that in North Dakota the mean temperature for July, 1916, was the hottest on record, being 4.7° F. above normal, and that for July, 1935, the next hottest. Extremely severe stem-rust epidemics occurred in both these years.

Stakman and Lambert (207), in a study of the effect of temperature on stem-rust development in the Upper Mississippi Valley (Minnesota, South Dakota, and North Dakota), found that for the period studied (1904-1925, inclusive) there was "a tendency for destructive epidemics to develop in warm growing seasons and for cool seasons to be comparatively free from rust." There were no destructive epidemics in seasons with an average temperature below 61° F., and no season with an average temperature above 64° F. escaped having one, although in seasons with intermediate temperature (61°-64° F.), stem rust was epidemic in some and not in others. Later, Lambert (113) showed that the odds were 6 to 1 that the occurrence of stem-rust epidemics in hot growing seasons was not due to chance. He pointed out, however, that in the period studied there occurred three noteworthy exceptions, namely, the years 1904, 1910, and 1916. The growing season (May, June, and July) in 1904 was moderately cool but stem rust was severe; in 1910, June and July were hot but stem rust was light; and in 1916, May and June were cool but stem rust was exceedingly destructive. In the latter year, however, the month of July was very hot.

These findings are in general agreement with those of several other investigators elsewhere. In Uruguay, Gassner (71, 72, 73) observed that stem rust flourished in the hot summer months but decreased in prevalence with the approach of autumn. Cotton (43) reports that stem rust was heavier in England in 1919 than in 1920, a condition which he attributes in part to the warmer weather of the former year. Chabrolin (37) claims that, in Tunis, a wet March followed by a dry, hot April is conducive to a heavy stem-rust attack. This observation, he states, was made much earlier by Boeuf. Zekl (238) asserts that seasons of heavy rust infections are usually characterized by great heat. Vasey, Balwin, and Doery (222) state that, in Victoria, Australia, stem rust did serious damage in 1916 and 1934. The main attack developed in the first week of November, a period of high temperatures combined with high humidity.

Cool growing seasons have usually, although not always, been regarded as unfavourable to stem-rust development. Bailey (10) suggests that the failure of stem rust to reach epidemic proportions in Manitoba in 1924 was due to the cool weather that prevailed during the latter part of the growing season. Peltier (157) states that, in Nebraska, low temperatures are apparently the major limiting factor in the development of primary infection and in the subsequent development of uredia. Johnston, Melchers, and Millar (107) are of the opinion that minimum temperatures are more important in relation to infection than are maximum or mean temperatures, as it is not until minimum temperatures become high enough to favour abundant infection that stem rust becomes severe in the State of Kansas. Melchers and Johnson (140) believe that frequent night temperatures of below 60° F. from May 15 to June 24 in 1938 were largely responsible for holding stem rust in check in Kansas in that year. On the other hand, Bolley (23) and Freeman and Johnson (67) suggest that the low temperature which prevailed during the growing season of 1904 was partly responsible for the severity of the attack which developed in the Upper Mississippi Valley in that year. Similarly, Zimmermann and Schneider (240) believe that the abnormal weather in Mecklenburg during July, 1909, when the temperature fell as low as 42° or 43° F., contributed to the development of

the severe outbreak that occurred in that year. Lambert (113) points out that stem rust may become epidemic in a cool season if other conditions favouring its development are present, as happened in 1904 in the Mississippi Valley.

Temperature in Relation to Outbreaks of Stem Rust in Western Canada

From the foregoing discussion, it is evident that temperature may profoundly influence stem-rust development. As in Western Canada stem rust is much more severe in some years than in others and in some areas than in others, temperature data have been studied to ascertain to what extent this variability in the amount of infection may be attributable to temperature conditions in the different years and areas.

Seasonal Temperatures. Temperature data for the months of May, June, July, and August are presented in Tables 15 and 16. During the month of May, temperature can have no direct influence on stem rust in Western Canada, as the disease is never present during that month. To a large extent, the same is true for the first half of June, as the disease is not usually visible in the field until towards the end of June, and in some years not until after the beginning of July. The temperature data for May and the first half of June are given consideration largely because of the influence that spring and early summer temperatures may have on crop development.

TABLE 15.—MEAN TEMPERATURE IN MANITOBA, SASKATCHEWAN, AND ALBERTA, BY METEOROLOGICAL DIVISIONS, FOR THE 4-MONTH PERIOD MAY TO AUGUST, AND FOR THE 3-MONTH PERIOD JUNE TO AUGUST, FROM 1916 TO 1938, FOR YEARS IN WHICH STEM RUST WAS LIGHT, MEDIUM, AND HEAVY IN THE DIVISIONS INDICATED

Meteorological Division	Months	Light	Medium	Heavy	23-year period
		° F.	° F.	° F.	° F.
<i>Manitoba</i>					
Red River	May - August	62.5	62.1	61.4	62.2
	June - August	65.3	65.4	64.8	65.2
Qu'Appelle and Assiniboine Rivers	May - August	61.3	61.1	59.7	60.9
	June - August	64.1	64.4	63.3	64.0
<i>Saskatchewan</i>					
Qu'Appelle River	May - August	60.1	60.7	58.6	59.9
	June - August	62.7	63.7	61.8	62.7
Saskatchewan Forks	May - August	59.7	59.5	—	59.7
	June - August	62.6	62.2	—	62.2
South Saskatchewan River	May - August	60.3	60.0	—	60.3
	June - August	63.2	63.0	—	63.0
North Saskatchewan River	May - August	58.8	59.2	—	58.5
	June - August	60.5	61.7	—	60.7
<i>Alberta</i>					
Bow River	May - August	58.5	58.2	—	58.5
	June - August	61.4	60.9	—	61.3
Red Deer River	May - August	57.0	56.9	—	56.9
	June - August	59.4	59.9	—	59.5
North Saskatchewan River	May - August	56.4	56.3	—	56.4
	June - August	58.6	59.3	—	58.7

TABLE 16.—MEAN TEMPERATURE IN MANITOBA, SASKATCHEWAN, AND ALBERTA, BY METEOROLOGICAL DIVISIONS, FOR THE MONTHS OF MAY, JUNE, JULY, AND AUGUST FROM 1916 TO 1938, FOR YEARS IN WHICH STEM RUST WAS LIGHT, MEDIUM, AND HEAVY IN THE DIVISIONS INDICATED

Meteorological Divisions	May			June			July			August		
	Light	Medium	Heavy	Light	Medium	Heavy	Light	Medium	Heavy	Light	Medium	Heavy
<i>Manitoba</i>	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.
Red River	54.0	52.6	50.8	62.5	63.0	61.2	67.8	67.9	69.4	65.3	65.6	64.2
Qu'Appelle and Assiniboine Rivers	52.9	51.3	49.2	60.9	61.6	60.0	66.7	66.8	68.4	64.3	64.8	61.4
<i>Saskatchewan</i>												
Qu'Appelle River	51.8	51.5	48.2	59.7	61.7	58.8	65.7	65.7	66.8	62.7	64.0	60.4
Saskatchewan Forks	51.8	50.9	—	59.3	60.7	—	65.6	65.1	—	62.2	61.5	—
South Saskatchewan River	51.5	50.5	—	59.9	61.5	—	66.6	66.5	—	63.2	61.5	—
North Saskatchewan River	50.7	50.0	—	57.6	60.7	—	63.6	64.5	—	60.3	60.5	—
<i>Alberta</i>												
Bow River	50.6	50.0	—	58.1	58.5	—	64.4	64.5	—	61.6	60.0	—
Red Deer River	49.7	47.6	—	56.8	58.0	—	62.3	63.0	—	59.2	59.0	—
North Saskatchewan River	49.7	47.5	—	56.5	58.0	—	61.4	62.0	—	58.3	58.0	—

Table 15 contains for each meteorological division and for each class of years the general means of the average daily temperature for the 4-month period May to August and for the 3-month period June to August. From this table, it is evident that, in Western Canada, temperatures during the 3-month period, or even the 4-month period, are very satisfactory for urediospore germination, being in fact within the optimum range of temperature for this process. As pointed out earlier, this range is somewhat lower than the optimum range for the development of the organism within the host tissue. The mean temperatures for the 3-month period in the first five of the divisions lie within the latter range or near its lower limit, but in the other four divisions somewhat below that limit, although within the range at which stem rust will develop. Temperatures are usually lower in June than in July and August, and, as there is usually little stem rust present in June, the mean temperatures for the period in which stem rust is generally present (July and August) are somewhat higher in all divisions than those indicated for the three months.

A comparison of the mean temperatures for the different classes of years, shows that in the first three meteorological divisions, that is to say in the bad rust area, the general mean for the 4-month period is slightly lower in the heavy rust years than in the light rust years. The same is true of the 3-month period in these divisions. In seven of the nine divisions, the means for the 4-month period are slightly lower in the medium rust years than in the light rust years, although, in six divisions, the means for the 3-month period (June to August) are higher in the medium than in the light rust years. This fact would indicate that temperatures in May of the medium rust years were somewhat lower than those of the light rust years. Evidently then, in the bad rust area of Western Canada, there has been a tendency for the temperature to be slightly lower in heavy rust years than in light rust years. On the other hand, there has been a tendency in the medium rust years for the growing season (June to August) to be slightly warmer than in the light rust years. The differences in temperatures are so small that they probably have no significance. It will be observed, however, that the mean temperature for the growing season in the heavy rust years was above the minimum temperature limit (61° F.) given by Stakman and Lambert (207) for the development of epidemics in the Upper Mississippi Valley. Medium infection, however, developed in Northern Alberta in years 1927 and 1938 when the mean temperature for the growing season was slightly below that minimum.

Monthly Temperatures. To determine what relation the average monthly temperatures of May, June, July, or August may have to the occurrence of severe outbreaks of stem rust, the temperature data for the three classes of years are summarized by months in Table 16 for each of the meteorological divisions. In the first three divisions, the general means of of the average daily temperature for May, as well as for June and for August, is somewhat lower in the heavy rust years than in the light rust years, but for July somewhat higher. In all divisions, temperatures for the medium rust years are lower in May but higher in June than those for the light rust years, so that the average temperatures for these two months in both classes of years tend to become equalized. It appears, therefore, that cooler weather generally prevailed in the spring and early summers of

the heavy rust years than in the same months of the other two classes of years. August temperatures for the medium and for the light rust classes of years are so similar that the differences between them are probably of no significance whatever. It will be observed that medium rust development occurred in four of the divisions in years when the average temperature in August was below that usually considered satisfactory for stem-rust development.

The critical month for stem rust in Western Canada is July. Unless epidemic conditions become fairly well established in that month, damage to crops is usually of minor importance, although the year 1927 is an outstanding exception to this general rule. In Alberta, most of the development occurs in August, but as the development of stem rust in Western Saskatchewan seems to govern to a considerable extent the development in Alberta, July may be regarded as indirectly the critical month of stem-rust development in Alberta. Temperatures in July have, therefore, a direct influence on stem-rust development in the first six meteorological divisions and at least an indirect one on the other three.

In all the divisions and in all classes of years, the general temperature means for July were above 61° F. In most of the divisions, the general means for July were optimum or approximated the optimum for stem-rust development. It would seem, therefore, that in the first three divisions, which include the bad rust area, temperatures in July of the light rust years were quite suitable for stem-rust development, and were not an important deterrent in most of the other divisions. It is true that in 1916 the mean temperature for July was 60° F. in the North Saskatchewan River division of Saskatchewan, and that stem rust was comparatively light in that division, although moderately heavy in the Saskatchewan Forks division, immediately to the east of it, and severe in all of Eastern Saskatchewan. But infection was light also in the South Saskatchewan River division (south-western Saskatchewan), although the mean temperature for July of that year was 66° F. It is probable, therefore, that in the North Saskatchewan River division the failure of stem rust to reach moderate or severe proportions in 1916 was not altogether due to the comparatively low July temperature.

Whether or not in the heavy rust years the slightly higher temperature in July can be regarded as of definite significance in promoting epidemic conditions is not readily determinable. The higher temperature would tend to shorten the incubation period of each rust generation, thereby permitting more generations to be produced, but it would also tend to increase evaporation and thus remove surface moisture from the plants, thereby reducing the opportunities for infection. Furthermore, it would hasten the maturing of the crop and thus tend to offset any advantage the disease might gain from a more rapid development. The differences between the mean temperatures for July in the heavy and the light rust years are so small, being less than 2° F., that it is questionable if the differences were great enough to have any appreciable influence on the development of the disease.

Daily Minimum Temperatures. With regard to the fluctuations in daily temperatures, it may be said that summers in Western Canada are characterized by hot days and cool nights. Actually, the lowest tempera-

ture during the day usually occurs in the early morning hours, just before or after sunrise. As a general rule, day-time temperatures are sufficiently high to promote rapid stem-rust development. Any retardation of development that occurs on account of low temperatures must largely be attributed to late night and early morning temperatures. Johnston and associates (106, 107) point out that minimum temperatures have a greater influence on stem-rust development than have maximum or mean temperatures, and this view is further developed by Melchers and Johnston (140), who attribute the unusually slow establishment of stem rust in the State of Kansas in 1938 to the relatively low minimum temperatures that prevailed between May 15 and June 24, the usual period of rapid stem-rust spread in that state. These authors accept 60° F. as the minimum temperature favourable for infection and subsequent stem-rust development, and show that periods with minimum temperatures of 60° F. or above in 1938 were short and were separated by periods with unfavourable minimum temperatures, while in 1935 and 1937 periods favourable for infection were prolonged. They point out that if 55° F. were chosen as the lowest favourable temperature, the contrast between 1938 and the other two years would be still more striking. Similarly, Melchers (139) points out that in 1940 "favourable, prolonged minimum temperatures extended much further into June and July than ordinarily occurs in Kansas," and attributes to this condition the severe outbreak of stem rust in the south-central part of that state, where the wheat crop was upward of two weeks late.

The conclusion of these authors seems all the more plausible when considered in relation to the finding of Hart (81) and Hart and Forbes (82) that infection only occurs with difficulty while the stomata of the plants are closed, that is to say, from late afternoon until shortly after sunrise, and that the majority of the infections take place during the remaining morning hours, until the dew on the plants dries. As mentioned above, the minimum temperature for any given day in Western Canada is usually reached in early morning, shortly before or after sunrise. It would, therefore, appear that the inhibitory influence of a low minimum temperature would be most pronounced just about the time that the inhibition would be most effective in preventing infection, namely, when the stomata are open and dew on the plants afford moisture conditions favourable for infection. On the other hand, the ability of closed stomata to exclude germ-tubes seems to be a good deal less in some wheat varieties than in others, and in all varieties, apparently, a considerable amount of infection takes place even when the stomata are closed (82, 159): Whether or not a minimum temperature somewhat below 60° F. increases the effectiveness of closed stomata to exclude germ-tubes remains to be determined.

With a view of determining the relation of minimum temperatures to stem-rust development, a study has been made of the daily minimum temperature at four stations in Western Canada, namely, Winnipeg, Minnedosa, Qu'Appelle, and Saskatoon, from June 20 to August 4 for the three classes of years from 1916 to 1938. The four stations may be regarded as more or less representative, respectively, of the first, second, third, and fourth meteorological divisions under discussion; and the period June 20 to August 4 corresponds with the period in which stem rust first appears and becomes established in Manitoba and the eastern half of

Saskatchewan. For the sake of more exact comparison, the period June 20 to August 4 is divided into three approximately fortnightly intervals. Of the three intervals, the second and third are the most important in respect to stem-rust development. Table 17 gives the general means of the minimum temperatures for the three intervals at the four stations in the three classes of years.

There is evident in Table 17 a general tendency for minimum temperatures to be somewhat lower in the light rust years than in the other two classes of years. This tendency is, however, more evident in the first and second fortnightly intervals than in the third (July 21-August 4). In fact, at Qu'Appelle and Saskatoon, the tendency is almost reversed in the third interval, and it is in that interval that stem rust usually makes its most rapid increase in eastern Saskatchewan. This fact would seem to indicate that the lower minimum temperatures in the other two intervals and the lightness of the stem-rust attack were not very closely related in the light rust years. This view is supported by the fact that the general means for the three intervals are higher (except in one instance) at Winnipeg in the light rust years than they are for the same respective intervals at the other three stations in the medium or heavy rust years. It would be expected that if the comparatively low minimum temperatures in the light rust years were mainly responsible for holding the disease in check at Winnipeg, the still lower minimum temperatures at the other three stations in the medium and heavy rust years ought to have curtailed stem-rust development to a greater extent. Instead, however, of any marked curtailment in the amount of infection due to the lower minimum temperatures at these three stations, moderate or severe epidemic conditions developed.

TABLE 17.—GENERAL MEANS OF THE MINIMUM TEMPERATURES FOR THE PERIODS JUNE 20 TO JULY 4, JULY 5 TO JULY 20, AND JULY 21 TO AUGUST 4, FROM 1916 TO 1938 AT WINNIPEG, MINNEBODA, QU'APPELLE, AND SASKATOON, FOR YEARS IN WHICH STEM RUST WAS LIGHT, MEDIUM, AND HEAVY IN WESTERN CANADA

Station	Period	Light	Medium	Heavy
		° F.	° F.	° F.
Winnipeg	June 20 - July 4	53.1	55.8	55.8
	July 5 - July 20	56.3	58.3	59.6
	July 21 - Aug. 4	55.9	55.5	56.4
Minnedosa	June 20 - July 4	49.5	52.5	51.6
	July 5 - July 20	52.5	54.5	56.7
	July 21 - Aug. 4	52.1	51.3	53.7
Qu'Appelle	June 30 - July 4	49.2	53.3	51.1
	July 5 - July 20	52.4	53.9	55.1
	July 21 - Aug. 4	51.6	51.0	51.5
Saskatoon	June 20 - July 4	49.7	52.4	—
	July 5 - July 20	52.9	54.3	—
	July 21 - Aug. 4	52.5	52.4	—

From the data of Table 17, it may be inferred that the percentage of days, between June 20 and August 4, with a minimum temperature of 60° F. or higher was less in the light rust than in the medium or the heavy

rust classes of years. This relationship is most pronounced at Winnipeg, less so at Minnedosa, and almost or completely disappears at Qu'Appelle and Saskatoon. The percentage of days with minimum temperatures of 60° F. or higher, for the light, medium, and heavy rust classes of years was respectively, 23, 30, and 37% at Winnipeg; 11, 15, and 20% at Minnedosa; 12, 11, and 14% at Qu'Appelle; and 11 and 11% for the first two classes at Saskatoon.

These data, however, do not take into account the distribution of such days. Melchers and Johnston (140) and Melchers (139) emphasize the particularly favourable influence on infection of the occurrence of extended periods in which the minimum temperature did not fall below 60° F., that is to say, periods of several or more consecutive days with such temperatures. By way of summarizing the data germane to this point for the 23 years under review, it may be said that for the light medium, and heavy rust classes of years, respectively, the average number of periods of 2 days or more on which the minimum temperature was 60° F. or higher per year between June 20 and August 4 was, for Winnipeg, 2.5, 3.1, and 4.4 days; for Minnedosa, 1.0, 1.1, and 2.2; for Qu'Appelle, 1.1, 0.8, and 1.6; and, for Saskatoon, 0.8 and 0.8 (light and medium rust classes). From these data, it is evident that, except at Winnipeg, there was very little difference in the average number of such periods for the light and medium classes of years. It is evident, too, that the average number of such periods per year was greater at Winnipeg in the light rust years than at Minnedosa in the heavy rust years, and still greater than Qu'Appelle.

If a period of 3 consecutive days with minimum temperatures of 60° F. or higher is considered, the average number of periods per year are reduced, being for the light, medium, and heavy rust classes of year, respectively, as follows: for Winnipeg, 1.1, 2.1, and 2.8 days; for Minnedosa, 0.6, 0.8, and 1.2 days; for Qu'Appelle, 0.5, 0.0, 0.2 days; and for Saskatoon, 0.4 and 0.2 days (light and medium rust classes).

The data just presented for Winnipeg, and to a lesser extent those for Minnedosa, seem to support the view that years with a high frequency of periods with minimum temperatures of 60° F. or above tend to be associated with years of heavy infection. And, indeed, from what is known of the relation of temperature to infection, this would be expected. On the other hand, at Qu'Appelle, and more so at Saskatoon, the data are less in agreement with this view, and, to some extent, they are contradictory to it. Only on one occasion (July 15 to 22, 1923) in the five heavy rust years was there at Qu'Appelle a period of three or more consecutive days on which the mean minimum temperature was 60° F. or higher. There was none in the medium rust years. If such periods were necessary to promote severe infection, no epidemics would be expected to have occurred in the area represented by this station. At Saskatoon, in the nine years that stem rust was of moderate intensity in that area, there was only one occasion (July 8 to 10, 1916) on which the minimum temperature was 60° F. or higher on 3 or more consecutive days; and only on seven occasions in those years had 2 consecutive days such minimum temperatures. At none of the stations, except Winnipeg (June 27 to 30) and Qu'Appelle (August 13 and 14), in 1927 was there any period of 2 or more consecutive days with minimum temperatures of 60° F. or higher between June 20 and August 30,

yet epidemic conditions were fairly well established by the middle of August in Manitoba and by the end of August in eastern Saskatchewan. The single period of 4 days (June 27 to 30) at Winnipeg had little influence on the development of stem rust, as inoculum was scarce at that time, but it is very likely that the 2-day period (August 13 and 14) at Qu'Appelle had a definite influence in promoting infection, as inoculum was then abundant. In 1938, as Figure 8 shows, only on one occasion (July 3 to 6) was the minimum temperature between June 20 and August 10 at Minnedosa 60° F. or higher for 2 or more consecutive nights, and only on two occasions at Qu'Appelle. During most of the time, minimum temperatures were considerably below 60° F. The likelihood is, however, that much infection did occur during the periods just indicated, as it is known (Table 2) that inoculum was plentiful shortly before or on those days.

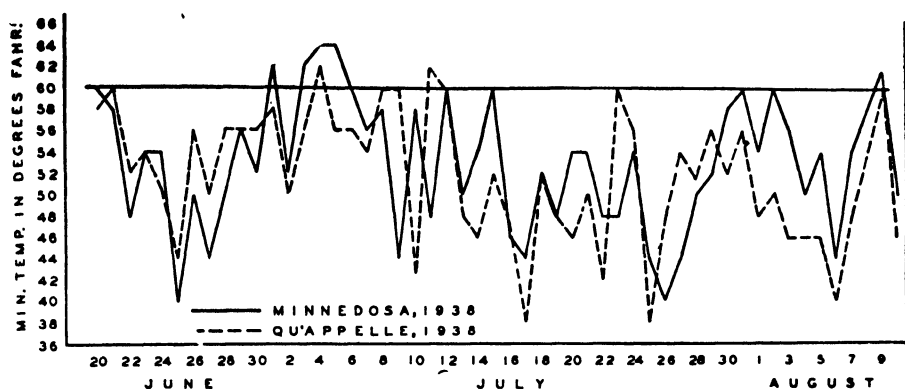


FIGURE 8. Graph showing daily minimum temperatures (in degrees Fahrenheit) from June 20 to August 9, 1938, at Minnedosa, Man., and Qu'Appelle, Sask.

There is a relationship, at least a partial one, involved in this general question of the influence of high minimum temperatures on the amount of infection, and it is, namely, that periods of high minimum temperatures sometimes, but not always, accompany periods of south wind, and periods of south wind occurring between June 20 and August 4 are not infrequently associated with spore showers of stem rust. The amount of inoculum present during some of the periods of high minimum temperatures is, therefore, likely to be greater than when the minimum temperatures are low and the wind is from some other direction. This relationship will be touched on later in connection with the interrelation of different meteorological factors on stem-rust development.

Unfortunately, there seems to be no experimental evidence to show to what extent or in what manner comparatively short daily exposures to temperatures somewhat below 60° F. interfere with stem-rust infection, or even that such exposures actually do reduce the amount of possible infection. Only occasionally in Western Canada would the temperature fall low enough in summer to interfere with urediospore germination, as the optimum for this process seems to lie between 53° and 63° F., and some germination occurs at as low a temperature as 35° F., and even just above the freezing point (137). Minimum temperatures, therefore, between 50° and 60° F. could hardly be expected to interrupt seriously the entrance of

the germ-tubes into the stomata, unless, indeed, such temperatures make the stomata more resistant to penetration of the germ-tubes. In at least some races of stem rust, infection proceeds readily below 60° F. For instance, Peltier (151) found that the lower limit for optimum infection with Race 9 on certain wheat varieties in the heading stage was 50°, and with Race 3, it was 57° F., while Melander (137) states that Race 35 of wheat stem rust, Race 2 of oat stem rust, and Race 7 of rye stem rust, respectively, readily infected seedlings of wheat, oats, and rye at the former temperature. Stakman and Levine (208) found that infection would take place at as low a temperature as the host plant could stand. It is true, of course, that growth of the organism in host tissue is appreciably slowed down at temperatures of 60° F. or less, and, at about 50° F., is generally largely suspended. This suspension of growth may possibly be mainly due to nutritional difficulties, and if so would not probably affect the germinating spore or the growth of the germ-tube on the surface of the plant. Apparently it might be easier to explain the observed retardation in the increase of stem rust by attributing it to the effect of minimum temperatures of less than 60° F. on the organism after it has penetrated through the stomata, rather than to any appreciable failure of the germ-tubes to gain entrance into the plants because of such temperatures. The effect of the higher minimum temperatures may be largely to favour the rapid establishment and promotion of the parasitic relation of host and organism.

RELATION OF LIGHT TO STEM-RUST DEVELOPMENT

Light is essential for the growth of chlorophyll-bearing plants, and, as the stem-rust fungus cannot maintain itself apart from its hosts, it is evident that light is indispensable, at least in an indirect way, to the development of the disease. Furthermore, the stomata of plants open as a response to light and may thereby facilitate the entrance through them of the germ-tubes, a primary requisite of infection. Germination, of course, must first take place. Arthur (7) states that the germination of rust spores proceeds more freely at night. Bruschetti (28) claims that, in his experiments, neither light nor darkness had any influence on the germination of urediospores, while Sibilia (184) found that urediospores of stem rust, as well as of three other cereal rusts, did not germinate in the absence of light. At the time this section was being written, the author dusted freshly collected stem-rust urediospores on tap-water contained in a watch-glass, placed the watch-glass in a cabinet, inverted a small earthenware jar over the watch-glass, and shut the door of the cabinet. The spores were, therefore, in extreme darkness, but, in less than 3 hours, from 30 to 40% of the spores were showing vigorous germ-tubes with a length of two, three, and four times the diameter of the spores.

On the other hand, bright sunlight directly affects the germinability of urediospores during exposure, although the effect seems to be only temporary and not detrimental. Bolley (22) found that urediospores exposed on a watch-glass to bright sunshine in August for 21 hours fell in germination from 90 to 100% to 8 to 15%. In this instance, the injury was probably largely due to heat and rapid desiccation rather than to any direct effect of light; for later Bolley and Pritchard (24) exposed spores to sun and air during the entire month of August and found over 5% of the spores

germinable at the end of the month. Stock (214) found that urediospores of leaf rust of wheat and of rye, and of crown rust, germinated equally well under the illumination of a 500-watt lamp as in darkness, but that the germination of urediospores of stem rust was retarded under the light, and development only reached parity with that of the spores in darkness after 8 hours. Weston (234, 235) showed that urediospores of stem rust do not germinate while exposed to bright direct sunlight or to very strong diffuse sunlight. The germinability of the spores was, however, not adversely affected, for the same spores germinated afterwards when they were placed in darkness or subdued light. He states that exposure (on the surface of water) for several hours to direct sunlight when the day temperature is high may kill urediospores, but points out that the killing is due to heat, not to light. Gassner and Straib (76) found that urediospores are little affected by exposure to direct sunlight. On the other hand, Hwang (97) found a direct relation between low light intensity and retention of spore viability. At low light intensities (daily maximum 1,500 foot-candles), the germination of urediospores was reduced to about 10% after an exposure to sunlight for 270 hours, while, at moderately high light intensity (daily maximum 7,000 foot-candles), it was reduced to 10% by an exposure to sunlight for 75 hours.

To what extent the entry of the fungus into the host may be affected by light seems unclear. Gassner (71) obtained just as good infection on plants that were shaded in a room as on those exposed to light. Stakman and Piemeisel (212) state that, owing to the usually more favourable moisture conditions, best infection usually occurs at night. Lauritzen (115) found as high a number of plants infected among those incubated for 24 hours in darkness as among those incubated for the same number of hours in the greenhouse where they were exposed to the light prevailing at the time of the experiment, namely, that of cloudy winter days. His results are similar to those obtained by Stakman and Levine (208) with plants incubated in low and high light intensities. In neither case is the number of infections per plant indicated. With plants kept in incubation chambers for 48 hours in darkness, in different artificial light intensities, and in sunlight, Peltier (155) obtained as many plants infected and as much infection per plant on those plants incubated in darkness as in those incubated in sunlight or under the artificial lights. Gassner and Straib (76), on the other hand, obtained very weak infection in plants subjected to darkness for 2 days after inoculation and no infection in those subjected to 4 days of darkness after inoculation, while, in those kept under clear glass, good infection resulted. Hart (81) and Hart and Forbes (82) observed a marked reduction in the number of infections on several wheat varieties kept in darkness during the incubation period following inoculation. They attribute this result, not to any failure of the spores to germinate in darkness, but to the inability of the germ-tubes to enter the stomata, which remain closed in response to the darkness. On some varieties the inhibitory effect of darkness was more pronounced than on other varieties. Peterson (159), however, obtained satisfactory infection on certain strains of wheat under conditions of darkness. As suggested earlier, the amount of infection on certain strains of wheat under conditions of darkness may possibly vary somewhat with the host varieties used in the test, and of

course with the suitability of the moisture and temperature conditions in the incubation chambers. Further elucidation of the effect of darkness on stem-rust infection would seem necessary.

With regard to the development of the organism in the host tissue, there is general agreement that bright light induces most vigorous and rapid growth. Gassner (71) showed that strong light increased the susceptibility of the host, or, in other words, promoted vigorous rust development. Stakman and Piemeisel (212) state that a considerable amount of sunlight is necessary for best rust development, and that cloudy weather may lengthen the incubation period by a week or more. Shaded plants were invariably more weakly infected than those exposed to direct sunlight. Stakman and Levine (208) found that stem rust developed better in fairly high light intensities than in lower light intensities, and Peltier (155), that best development occurred in strong light. Gassner and Straib (76) by supplementing the low sunlight in winter by means of a 1,000-watt lamp, shortened the incubation time of the rust by from 1 to 2 days. Periods of darkness subsequent to inoculation lengthened the time of incubation. Forward (63) showed that exposure to darkness after inoculation delayed pustule formation proportionately to the length of the exposure to darkness. Melander (137) found that a reduction in light intensity retarded rust development. Levine (118) concluded from his study (which embraced stations in the Upper Mississippi Valley and Western Canada) that in the years 1919 to 1923 the normal light intensity during the growing season appeared quite sufficient for the best development of stem rust. Butler and Hayman (32) and Moreland (143) point out that in India heavy rust infection usually occurs in cloudy seasons, but from their accounts the infection seems to be influenced by the greater moisture associated with the cloudiness rather than by the decrease in bright sunshine, of which there is probably an ample amount for stem-rust development in any year. Lambert (113) states that in the Mississippi Valley stem-rust epidemics seem to occur in years that have the greatest number of clear days during the growing season, but he considers that this relationship may probably be only incidental, the more likely reasons being the higher temperature and the more abundant dews in such seasons. To insure satisfactory stem-rust development, it is now a well established practice in the more northerly latitudes to supplement the daylight of the short winter days by means of artificial illumination.

The growth response of the organism to light seems to be very closely associated with that of the host plant. As suggested by Stakman and Levine (208) and by Peltier (155), the effect on the organism is probably largely indirect. In bright light, the metabolic activity of the host plant is greater than in subdued light and as a consequence the nutritional requirements of the fungus are more adequately supplied.

The general experience that stem rust develops best in bright sunlight is not without its exception. Hart and Zaleski (83) found that under conditions of shade, plants of Hope wheat, a variety possessing a high degree of mature-plant resistance, became heavily infected with Race 21 of wheat stem rust, while similar plants of this variety exposed to normal summer sunlight were relatively free from infection. Johnson and Newton (105) showed that pronounced reduction in light intensity (60%) or in

daily hours of light during the growing period of the plants tended to lower the resistance of Hope wheat to Race 21 of stem rust, but concluded that deficiency of light decreased resistance only in conjunction with other factors that tended to induce greater succulence of the plant tissue.

Sunshine Hours in Western Canada

In the present study, consideration has been given to the total hours of sunshine for the three months June, July, and August at six stations situated within the zone severely affected by stem rust. The stations are Morden, Winnipeg, and Brandon in Manitoba, and Qu'Appelle, Indian Head, and Rosthern (40 miles north of Saskatoon) in Saskatchewan. Table 18 summarizes the data for the period from 1916 to 1938. From this table, it will be seen that the average number of hours of sunshine gives little indication as to which group of years had heavy rust attacks. For the individual months at the different stations, the respective means for June and July in the light rust years are as high as, or higher than, those in the heavy rust years, while in August the tendency is for the heavy rust years to have a somewhat higher number of hours of sunshine than the light rust years. The differences, however, appear to be too small to have any appreciable influence on the development of the disease in the crop. It seems, therefore, unlikely that in Western Canada the amount of sunshine has been more favourable to stem-rust development in one class of years than in another.

TABLE 18.—MEAN HOURS OF SUNSHINE FOR JUNE, JULY, AND AUGUST, FROM 1916 TO 1938, AT MORDEN, WINNIPEG, AND BRANDON IN MANITOBA, AND AT QU'APPELLE, INDIAN HEAD, AND ROSTHERN IN SASKATCHEWAN, FOR YEARS IN WHICH STEM RUST WAS LIGHT, MEDIUM, AND HEAVY IN MANITOBA AND EASTERN SASKATCHEWAN

Station	June			July			August		
	Light	Medium	Heavy	Light	Medium	Heavy	Light	Medium	Heavy
Morden	hr. 254	hr. 237	hr. 255	hr. 302	hr. 295	hr. 290	hr. 271	hr. 282	hr. 291
Winnipeg	258	255	256	306	285	296	269	278	278
Brandon	239	235	215	293	283	279	268	272	267
Qu'Appelle	275	281	258	328	337	321	289	297	290
Indian Head	222	234	215	291	301	284	247	261	262
Rosthern	276	268	—	335	328	—	283	285	—

RELATION OF WIND TO STEM-RUST DEVELOPMENT

The possibility that spores of cryptogamic plants may be carried long distances by winds or air currents was suggested as early as the opening of the nineteenth century, and since that time this means of spore dispersal has become more and more recognized as the principal one by which stem rust spreads. In 1805, Banks (11) surmised that the time necessary for rust infections to produce spores (?) is short, and says "if so, how frequently in the latter end of the summer must the air be loaded as it were with this animated dust, ready, whenever a gentle breeze, accompanied with humidity, shall give the signal to intrude itself into the pores of thousands of acres of corn." Darwin (49), from reports by others, and from his own observations of dust falling on ships several hundred miles out at sea, concluded that no one need be surprised at the wide dispersion of fungus

spores by wind. More recently, the importance of wind-borne spores in connection with the spread of cereal rusts was pointed out by Bolley (22, 23), and stressed by Klebahn (110, 111), Freeman and Johnson (67), and others. Within the last two decades, evidence both circumstantial and direct has been obtained which shows that the spread of stem rust from field to field and from one area to another is almost entirely brought about by winds. Lambert (113) was the first to attempt a comprehensive study of the relation of winds to outbreaks of stem rust; but, before further consideration is given to this aspect of the study, a brief explanatory statement should be made concerning wind direction.

Wind Direction Dependent on Position of Air-Pressure Areas

Wind is the result of the unequal distribution of air pressure over the earth's surface. Meteorological Services of different countries indicate the distribution of air pressure day by day for their particular region on the daily weather maps published by such Services. These maps show, for the regions concerned, the areas having high or low air pressure on the date of issue. Areas of high and of low air pressure are indicated by successive encircling lines, called "isobars," each of which passes through points of equal air pressure (reduced to sea level) in each air-pressure area. In a high pressure area, the air pressure is highest at the centre and decreases outward; while, conversely, in a low pressure area, the air pressure is lowest at the centre and increases outward. Each successive isobar represents an equal decrease, or increase, in air pressure. There is, therefore, a decreasing air-pressure gradient from the centre of a high pressure area to the centre of a neighbouring low pressure area. The positions of high and low air-pressure areas in North America are seldom stationary, but move across the continent in a general west-to-east direction. As a rule, a high pressure area succeeds a low pressure area, and a low a high, although their relative positions may change a good deal from day to day. In a high pressure area, the direction of the wind is clockwise and more or less parallel to the isobars, but inclining slightly outward from the centre. In a low pressure area, the wind moves in the opposite direction, namely, counter-clockwise, and more or less parallel to the isobars, but inclining inward towards the centre (Figure 9). The closer the isobars are to one another, that is to say, the steeper the air-pressure gradient, the greater is the wind velocity.

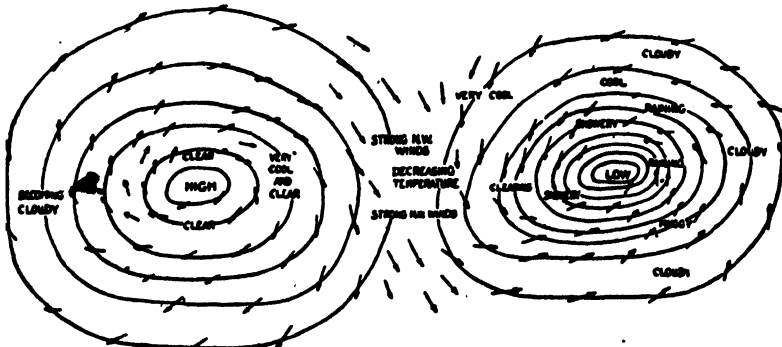


FIGURE 9. Diagrammatic representation of air-pressure distribution, showing associated wind directions and weather conditions. (After Patterson).

From what has been said, it is evident that if a low pressure area is following a high pressure area across this continent, the general direction of the wind between their centres will be from south to north. If, therefore, as they move eastward, their central portions occupy positions in the general region of the International Border, the direction of the wind, at all points in the southern part of Canada lying between the centres of the two pressure areas, will be southerly.

In the investigation already referred to, Lambert (113) studied the daily weather maps of the period May 20 to June 10, for the years 1901 to 1926, to ascertain on what days conditions were favourable to blow stem-rust spores from Texas northward to the spring-wheat area of the Upper Mississippi Valley, that is to say, on what days there was low air pressure to the west and high air pressure to the east of the Mississippi River, with more or less parallel isobars running north and south between them. He was unable to find any correlation "between the years in which conditions seemed to be the most favourable for the migration of rust from the south to the north and the years in which epidemics developed in the spring wheat area." He points out, however, that "southerly winds often sweep up the Mississippi Valley at the time the rust is most plentiful in the south, with sufficient velocity to carry spores from Texas to the spring wheat area in less than three days."

South Wind in Relation to Spore Showers

In the present study, with a view to ascertaining if any relation could be found to exist between the occurrence of south winds and the prevalence of stem-rust spores in the air over a part at least of Western Canada, an examination of the daily weather maps for the period June 12 to July 20, from 1916 to 1938, was made to determine on what dates the low pressure and the high pressure areas were so positioned as to bring a south wind to southern Manitoba. The dates are indicated in Table 19. The period June 12 to July 20 was chosen for the reason that before June 12 very few spores have been found on the slides, and after July 20 local inoculum has been usually sufficient in southern Manitoba to cause uncertainty as to whether a sudden increase in the number of spores on the slides should be attributed to wind-borne spores or to locally produced ones. Southern Manitoba was chosen because it is the area in which spores are earliest found on the slides, and in which stem rust almost invariably makes its first appearance in the field. If any association exists between winds and the prevalence of spores in the air, it should be most evident in this area, for Manitoba lies directly north of a cereal-producing region that extends from Texas northward to the Canadian border, and in that region stem rust is present in the south during early spring (April and May) and in the north during the latter part of June and throughout July (113). South winds that blow into Manitoba during June and July must pass over a rust-infected area, although in this area the severity of the infection varies greatly from year to year.

TABLE 19.—DATES ON WHICH LOW AND HIGH ATMOSPHERIC PRESSURE AREAS WERE IN SUCH A POSITION AS TO BRING A SOUTH WIND OF TWELVE HOURS OR MORE TO SOUTHERN MANITOBA BETWEEN JULY 12 AND JULY 20 OF THE YEARS 1916 TO 1938*

Date	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938
June 12	+	+	+	+	+	+	+	0	0	+	0	0	0	+	+	+	0	0	+	0	+	0	+
June 13	0	0	0	0	0	+	0	0	0	+	0	0	0	+	+	+	+	+	+	0	+	0	+
June 14	0	0	+	0	0	+	+	0	0	0	0	+	+	+	+	+	0	+	0	0	0	0	0
June 15	0	+	+	0	0	+	0	0	+	0	+	+	+	+	+	+	+	0	0	0	+	+	0
June 16	0	0	0	+	0	+	0	+	0	+	0	+	+	+	0	+	+	0	+	0	0	+	0
June 17	0	+	0	+	0	+	+	+	0	0	0	+	+	+	+	+	+	+	0	0	0	+	+
June 18	0	0	0	+	0	+	0	+	0	+	0	+	+	+	+	+	+	+	0	0	0	+	+
June 19	0	0	+	0	+	0	0	0	+	0	+	+	0	+	+	+	+	0	0	0	0	+	+
June 20	0	0	0	0	+	+	+	0	+	0	0	0	0	0	0	0	0	0	0	0	0	0	+
June 21	0	0	0	+	0	+	+	0	+	+	0	0	0	0	0	0	0	0	+	0	0	0	0
June 22	0	0	+	+	0	0	+	+	0	0	0	0	0	0	0	0	0	0	+	0	0	+	0
June 23	+	+	0	0	+	0	0	+	+	0	0	0	0	0	0	+	+	0	0	+	0	+	0
June 24	0	+	0	+	+	0	0	+	0	0	0	0	0	0	+	+	0	0	+	+	+	0	0
June 25	0	+	+	0	+	0	+	0	0	0	0	0	0	0	0	+	+	+	+	0	+	0	0
June 26	0	+	0	0	+	0	0	+	0	0	+	+	0	+	0	+	+	+	+	0	0	0	0
June 27	0	+	+	+	0	0	+	0	0	+	+	+	+	+	0	+	+	+	+	0	0	0	+
June 28	0	0	0	+	0	+	0	0	0	0	0	0	+	+	0	+	0	0	0	+	+	0	+
June 29	+	+	0	+	0	+	0	+	0	+	0	+	0	0	+	0	0	+	+	+	+	0	+
June 30	+	+	0	+	0	+	0	+	0	+	+	+	+	0	0	0	0	0	0	+	+	+	+
July 1	0	0	+	0	0	+	0	0	0	+	0	0	+	0	+	0	0	+	+	+	0	+	+
July 2	0	0	+	0	0	+	0	+	+	0	0	0	+	+	+	0	+	+	0	0	0	0	0
July 3	+	+	+	0	+	+	+	0	+	0	+	+	0	+	+	+	+	+	+	0	0	0	0
July 4	+	+	+	0	+	+	+	0	+	+	0	+	0	0	0	0	+	+	0	+	+	0	+
July 5	+	+	0	0	0	+	0	0	+	+	0	+	0	+	0	0	0	0	+	0	+	+	0
July 6	0	+	0	0	0	+	0	+	+	0	+	0	0	+	0	+	0	+	0	+	0	+	+
July 7	0	+	+	0	0	+	0	0	+	0	+	+	0	0	+	0	0	0	+	+	+	0	0
July 8	+	0	0	0	0	0	+	0	+	+	0	0	0	0	0	0	+	+	+	+	0	+	0
July 9	+	0	0	0	0	+	0	0	+	+	0	0	0	+	+	0	0	+	0	+	0	0	+
July 10	0	+	0	+	0	0	0	0	+	+	0	+	0	+	0	+	+	+	0	+	0	0	0
July 11	0	0	+	0	0	0	0	0	+	0	0	0	0	+	0	+	+	0	+	0	+	0	+
July 12	+	0	+	+	0	0	+	0	+	+	0	+	0	+	0	+	0	+	0	0	+	0	+
July 13	+	0	0	+	0	0	+	+	+	0	0	0	0	0	0	+	0	0	+	0	0	0	0
July 14	+	0	0	0	0	0	+	0	0	0	+	0	+	0	+	0	+	0	0	0	+	0	0
July 15	0	0	0	0	0	+	0	0	+	0	0	0	+	+	0	+	0	+	0	+	0	0	0
July 16	0	0	0	+	+	0	0	+	0	0	+	0	0	+	0	0	0	0	+	+	0	0	0
July 17	0	+	0	+	0	+	0	+	0	+	0	+	0	0	0	0	+	+	+	0	0	0	0
July 18	+	+	+	+	0	0	+	0	+	+	0	+	0	+	0	0	0	0	0	+	0	+	+
July 19	+	0	0	+	+	0	+	0	+	+	0	+	0	+	0	0	0	+	0	+	0	+	0
July 20	+	0	0	0	0	+	+	0	+	0	0	+	+	+	+	0	0	0	0	0	0	0	0
Total	15	18	15	18	13	23	17	15	21	19	11	19	13	22	16	16	14	19	18	16	17	14	19

* Such dates are indicated by the + sign.

It would, therefore, be expected that a sudden increase in the number of spores in the air over southern Manitoba would be associated with a period of south wind. That this is so is clearly brought out by a comparison of Tables 2 and 19. Two outstanding examples of this association may be mentioned by way of illustration, namely, June 12 to 19, 1929, and June 23 to July 2, 1935. It will be seen from Table 19 that during those periods the wind was prevailing from the south, and, from Table 2, that pronounced increases in the number of spores are associated with these periods. The positions of the two main air-pressure systems on June 17,

1929, and on June 23, 1935, are shown respectively in Figures 10 and 11. It will be seen from these figures that the air-flow between the

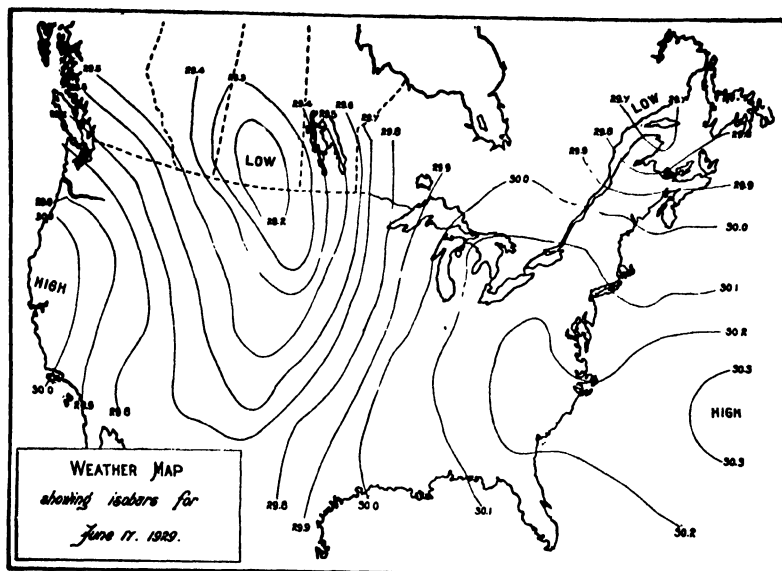


FIGURE 10. Air-pressure distribution in Canada and the United States on June 17, 1929. The closeness of the isobars east of the center of low pressure indicates a steep air-pressure gradient and strong (southerly) wind.

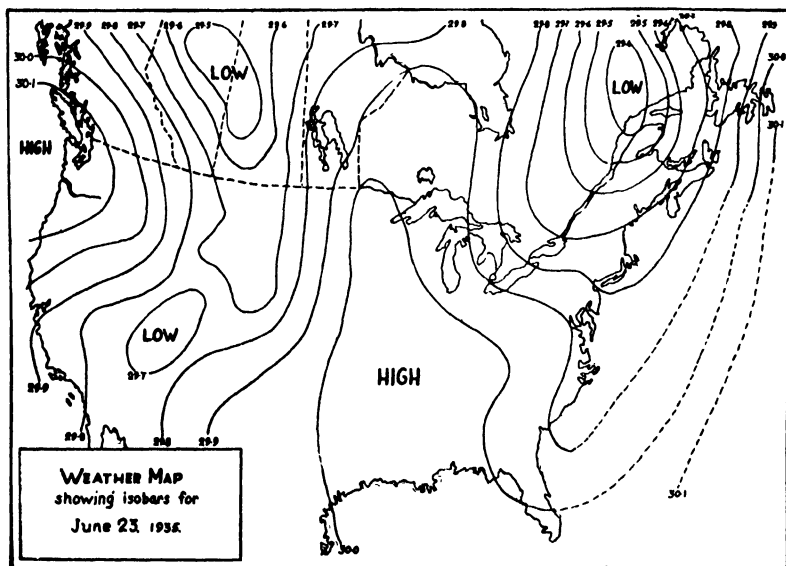


FIGURE 11. Air-pressure distribution in Canada and the United States on June 23, 1935. The wind direction is southerly in Manitoba and eastern Saskatchewan.

two air-pressure areas would cover a great part of the Mississippi Valley and, being from the south, would carry spores from there northward directly into Manitoba. Further examination of the two tables will show that, in practically every instance where there was a sudden increase in the

number of spores present on the slides, there occurred associated with this increase a period of south wind.

This association between spore showers and periods of south wind is further shown by the number of leaf-rust (*Puccinia triticea* Erikss.) spores on the slides. As each slide was examined for stem-rust spores, a record was made of the number of leaf-rust spores present. Usually leaf-rust spores appear somewhat earlier than stem-rust spores on the slides, but it is clear that there is a very close correlation between the occurrence of spore showers of leaf rust and of stem rust. Table 20 gives the number of

TABLE 20.—HOURS OF SOUTH WIND (SW., S., SE.) EACH DAY AT WINNIPEG, AND NUMBER OF UREDIOSPORES OF STEM RUST AND OF LEAF RUST INTERCEPTED DAILY BY ONE SQUARE INCH OF GLASS SLIDE EXPOSED AT WINNIPEG FROM JUNE 12 TO JULY 20, IN THE YEARS 1927, 1929, 1932, 1935, AND 1938

Date	1927			1929			1932			1935			1938*		
	South Wind	Stem Rust	Leaf Rust	South Wind	Stem Rust	Leaf Rust	South Wind	Stem Rust	Leaf Rust	South Wind	Stem Rust	Leaf Rust	South Wind	Stem Rust	Leaf Rust
	hr.	no.	no.	hr.	no.	no.	hr.	no.	no.	hr.	no.	no.	hr.	no.	no.
June 12	0	0	0	19	0	8	9	0	0	0	0	0	17	0	0
June 13	0	1	0	14	0	1	13	2	1	5	0	0	24	—	—
June 14	22	2	1	13	0	2	1	2	0	0	0	0	6	5	42
June 15	24	0	26	13	24	118	6	1	0	5	0	0	0	—	—
June 16	24	1	16	15	109	240	22	2	14	0	0	0	5	0	0
June 17	24	0	20	24	193	736	20	0	1	3	0	0	23	—	—
June 18	15	0	0	23	0	5	3	0	0	8	0	0	24	0	14
June 19	16	0	0	15	0	0	17	0	6	2	0	1	24	—	—
June 20	5	0	0	4	0	2	6	0	5	2	0	0	24	18	430
June 21	0	0	19	12	0	0	6	0	0	0	0	0	8	—	—
June 22	0	2	0	0	0	0	0	1	1	1	—	—	0	10	11
June 23	11	0	16	2	0	0	18	0	1	24	9	8	0	—	—
June 24	7	3	17	0	0	0	11	1	4	24	240	126	0	0	0
June 25	8	7	63	0	0	2	12	0	7	20	52	64	0	—	—
June 26	24	24	193	18	0	0	6	0	3	5	0	0	3	1	4
June 27	18	20	1150	12	0	0	5	0	0	0	0	6	15	—	—
June 28	11	0	2	9	1	2	2	—	—	23	10	9	24	86	110
June 29	23	4	10	11	0	1	0	—	—	24	16	41	24	—	—
June 30	12	0	8	10	0	0	9	1	2	23	38	79	14	328	451
July 1	0	0	3	1	0	0	0	1	1	24	8	10	22	—	—
July 2	9	0	1	17	0	0	17	0	0	17	21	32	0	2	43
July 3	23	0	5	16	2	8	12	0	0	5	7	3	18	—	—
July 4	19	38	23	3	0	2	20	0	0	18	12	5	17	0	21
July 5	21	22	37	0	0	0	3	0	1	0	5	4	20	—	—
July 6	1	0	0	21	4	10	0	0	0	2	0	2	15	4	116
July 7	21	11	15	7	—	—	6	0	0	19	1	3	2	—	—
July 8	5	7	0	3	3	12	14	8	24	17	0	0	0	3	180
July 9	0	0	0	13	2	8	1	1	1	15	3	0	17	—	—
July 10	20	0	11	23	481	1438	0	0	0	10	0	0	5	140	810
July 11	10	3	13	24	283	1029	13	10	18	3	3	2	23	—	—
July 12	13	2	22	0	0	0	1	0	2	0	12	2	16	247	1430
July 13	3	0	8	9	31	112	8	1	9	1	7	4	0	—	—
July 14	11	3	0	3	—	—	23	2	0	9	6	5	7	113	920
July 15	0	0	7	18	113	Numerous	14	0	3	14	51	10	3	—	—
July 16	0	1	13	23	4	—	0	4	8	22	1124	146	2	390	1840
July 17	12	4	30	0	3	—	15	7	17	1	5	3	2	—	—
July 18	1	6	8	0	34	—	9	15	25	13	380	66	16	880	4360
July 19	23	193	702	24	845	—	6	13	7	14	147	22	0	—	—
July 20	24	61	79	24	2138	—	0	80	80	3	357	182	0	200	82

* In 1938, the exposures were of 48 hours duration instead of 24 hours.

hours of south wind (S.E., S., S.W.) each day at Winnipeg, together with the number of leaf-rust and stem-rust urediospores on the slides exposed at Winnipeg from June 12 to July 20 for two light and three heavy rust years. The two periods just mentioned above are striking examples of this correlation.

As mentioned before, spores in the air are present earlier and are more numerous in June and July in southern Manitoba, especially in the Red River Valley, than elsewhere in Western Canada because this area lies directly in the path of south winds which sweep over that vast grain-growing area west of the Mississippi River. In Saskatchewan, at Indian Head and Saskatoon, the spore counts showed a relation between south winds and an increased number of spores in the air, but in the first part of the summer the number of spores was lower than in the Red River Valley, and periods of south wind that brought a large number of spores to the Red River Valley did not always bring an appreciable number to Saskatchewan. In fact, the earliest spore showers usually did not extend so far west as Indian Head. In Alberta, spore showers were not very pronounced, and those that did occur usually took place in the latter part of July or in August, and did not regularly coincide with periods of south wind.

The reason for these circumstances appears to lie in the fact that south winds reaching Alberta and, to a lesser extent, western Saskatchewan must pass, respectively, over a mountainous area where relatively little grain is grown or over the semi-arid Great Plains region where stem rust is usually of little consequence, and hence abundant inoculum for transportation northward is lacking. This statement is apparently not true of the year 1938, for in all probability, as indicated earlier, a great deal of inoculum was brought into these two areas by south wind, because of the unusual westward extension of heavy stem-rust infection in the Mississippi Valley in that year. The spore-bearing winds come largely from the south-east and east, and, as will be shown a little later, the winds adverse to the introduction of spores into these two areas markedly predominate.

Frequency of South Winds in Relation to Stem-Rust Outbreaks

To ascertain whether or not any association exists between years in which south wind was of particularly frequent occurrence during the summer and years in which epidemics of stem rust developed in Western Canada, relevant data are given in Table 21 for eastern Manitoba, the region where the association would probably be most readily discernible, if such an association actually exists. This table gives the total number of hours of south wind (S.E., S., S.W.) at Winnipeg between June 12 and July 20 from 1921 to 1938, and the total number of days between those two dates, from 1916 to 1938, on which low and high air-pressure areas were so positioned as to bring a south wind of 12 or more hours duration to eastern Manitoba. It will be observed that the average number of hours of south wind in the heavy rust years exceeded that in the light rust years by about 25 hours, and the average number of days with south wind was greater by one in the former than in the latter class of years. The fact, however, that, in the medium rust years, the average number of hours and of days with south wind are greater than in the other two classes of years, seems to indicate that a day more or a day less of south wind is not of much conse-

TABLE 21.—TOTAL HOURS OF SOUTH WIND (SE., S., SW.) AT WINNIPEG, MAN., BETWEEN JUNE 12 AND JULY 20 FROM 1921 TO 1938, AND NUMBER OF DAYS IN WHICH LOW AND HIGH ATMOSPHERIC PRESSURE AREAS WERE IN SUCH A POSITION AS TO BRING A SOUTH WIND OF TWELVE HOURS OR MORE DURATION TO SOUTHERN MANITOBA BETWEEN THE SAME DATES FROM 1916 TO 1938, FOR YEARS IN WHICH STEM RUST WAS LIGHT, MEDIUM, AND HEAVY IN THE PROVINCE OF MANITOBA

Light			Medium			Heavy		
Year	Hours	Days	Year	Hours	Days	Year	Hours	Days
1917		18	1919		18	1916		15
1918		15	1921	447	23	1923	350	15
1920		13	1924	601	21	1927	460	19
1922	374	17	1925	428	19	1935	376	16
1926	289	11	1930	422	16	1938	420	19
1928	308	13	1937	378	14			
1929	465	22						
1931	394	16						
1932	337	14						
1933	446	19						
1934	387	18						
1936	388	17						
Total	3308	193		2276	111		1606	84
Mean	376.4	16.1		455.2	18.5		401.5	16.8

quence. Actually, it is not so much the duration or frequency of south wind that matters but the amount of inoculum that it introduces. The likelihood is that in every year the number of hours or of days of south wind during the critical period for stem-rust infection is great enough to introduce ample inoculum to initiate an epidemic, if weather conditions are favourable and stem rust is abundant in the northern Mississippi Valley.

Wind from Other Directions in Relation to Spore Introduction

The evidence just presented indicates clearly an association in Western Canada between the occurrence of southerly wind and the presence of a high concentration of stem-rust inoculum in the air. In regard to westerly winds, they pass over the Pacific Northwestern States and British Columbia, areas traversed by high mountain ranges that run in a general north-to-south direction. These mountains, no doubt, present a considerable barrier to the eastward dispersal of fungal spores, but probably not an insurmountable one. The ranges are broken by passes, and it is quite possible that spores produced in the valleys or plateaux of these areas may be carried by surface winds eastward through such passes, or even across the mountain ridges themselves. At any rate, spread of stem-rust inoculum in the opposite direction, from the Mississippi Valley into the Western Highlands, is known to occur in some years (67, 85). Furthermore, both the Pacific Northwestern States and British Columbia lie in the zone of westerly winds, in which the upper winds are prevailing westerly. They are not retarded, as the surface winds are, by friction against the earth, and hence have usually a higher velocity than the surface winds. In mountain regions during summer, owing to the unequal heating

of the irregular land surface, strongly ascending air columns are commonly present. Spores carried up by these to higher levels would be carried eastward by the upper winds. Presumably, therefore, in spite of the mountain barriers, spores originating in these two areas west of the Rockies can be blown into Western Canada. As pointed out earlier, however, it is unlikely that any of the early inoculum or even any considerable amount of the later inoculum reaching Western Canada originates in these areas, although there is evidently the possibility that in occasional years a slight amount of the later arriving inoculum may do so.

Northerly winds play little or no part in the introduction of inoculum. They blow across a vast uncultivated area of even topography, and, were inoculum present in this area, could readily carry it into the cultivated area of Western Canada. As pointed out earlier, however, the growing season in the uncultivated area is later than in the cultivated area, and hence any inoculum arising on native grasses in the former area would be produced too late to have any influence on the course of stem-rust development in the latter area.

Easterly winds before reaching Manitoba, the most eastern portion of Western Canada, must pass over a territory several hundred miles wide, largely covered with forest or lake. In it, as mentioned earlier, the growing season is later than in Western Canada and cereal production is of comparatively little importance. The amount of stem-rust inoculum produced must be small, but there seems to be no good reason why some of what may be produced should not be carried by easterly winds into Western Canada, although this inoculum would arrive after stem rust became established in the latter area. East of this belt lie the main agricultural areas of Eastern Canada—eastern Ontario, Quebec, and the three Maritime Provinces—and the more northern Eastern States. The possibility of inoculum produced in these two areas being carried by winds to Western Canada seems, in general, to be rather slight.

The basis for this conclusion lies in the fact that, during the summer months, the air-pressure areas, as they pass eastward, are seldom if ever in a suitable relation or position to provide favourable winds for the purpose in question. As a rule, the high pressure areas pass south of the Great Lakes and most of the extensive low pressure areas pass over or north of these lakes, so that very rarely are the air-pressure areas in such a relation as to permit a flow of air from these two eastern areas into Western Canada. Furthermore, the movement of these pressure areas eastward is usually fairly rapid, and even were they temporarily in a suitable position for surface winds to carry spores westward, say from southern Ontario to Manitoba, it is doubtful if they would remain long enough in that position for the spores to reach their supposed destination. There is even less probability that spores could be carried westward by upper winds. The regions involved lie in the westerly wind zone, where the upper winds are prevailing from the west. An examination of meteorological maps giving the direction of the upper winds in these eastern areas during the summer months—the only period in which aerial dissemination of stem-rust inoculum has any significance for Western Canada—shows clearly that during these months the upper winds blow largely in an eastward direction. Presumably in all the years under review the same general tendency has

prevailed. The conclusion, therefore, seems to be justified that little or none of stem-rust inoculum reaching Western Canada originates in these eastern parts of the continent.

Prevalence of Winds Favourable to Spore Introduction

With a view of determining whether or not the hours of wind favourable to the introduction of stem-rust spores into different parts of Western Canada were appreciably greater than usual in heavy rust years, the mean hours of favouring wind for epidemic years and for the whole period (1922 to 1938) for which data are available are given in Table 22 for five stations for the three summer months. At most of these stations wind-hour records were initiated in 1922, and hence data for 1916, an epidemic year, and the next five years are not included. In the table the hours of wind favourable to spore introduction are printed in bold face.

TABLE 22.—MEAN HOURS OF WIND FAVOURABLE TO THE INTRODUCTION OF STEM-RUST SPORES IN JUNE, JULY, AND AUGUST, FOR FOUR HEAVY-RUST YEARS (1923, 1927, 1935, AND 1938) AND FOR THE 17-YEAR PERIOD 1922-1938 AT FIVE STATIONS IN WESTERN CANADA

Wind direction	Month	Winnipeg		Qu'Appelle		Scott		Lethbridge		Lacombe	
		Heavy-rust years	17-year period	Heavy-rust years	17-year period	Heavy-rust years	17-year period	Heavy-rust years	17-year period	Heavy-rust years	17-year period
		hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.	hr.
East	June	55.2	58.8	61.7	59.2	93.3	86.4	91.5	57.0	56.5	40.0
	July	44.0	47.2	44.7*	58.0	80.0	81.2	73.7	53.6	76.5	64.6
	August	51.5	56.3	51.5	57.6	63.7	60.1	76.7	51.5	49.0	48.2
Southeast	June	130.5	118.4	124.5	112.4	139.6	115.9	45.5	64.1	125.7	117.7
	July	144.0	131.9	85.7	124.5	80.5	116.2	66.2	75.1	95.7	117.9
	August	129.7	135.5	107.2	117.2	82.2	115.0	61.2	68.1	79.7	90.2
South	June	92.2	86.3	94.7	78.5	49.0	48.9	63.2	61.2	129.7	96.9
	July	92.7	100.7	69.7	74.5	62.0	65.0	65.7	60.1	114.0	128.5
	August	97.5	102.1	98.7	81.6	69.7	56.2	64.7	57.3	130.0	156.9
Southwest	June	59.5	82.0	84.7	105.4	54.2	77.7	96.0	153.5	86.0	88.8
	July	72.5	76.5	123.5	109.7	64.0	69.7	105.0	170.9	115.7	99.7
	August	92.5	92.8	112.2	128.6	88.0	74.3	124.2	165.0	122.5	107.0

* The figures in bold face indicate that at the respective stations the wind was favourable to the introduction of stem-rust spores.

Spore-bearing winds in the main can come only from four directions, namely, east, south-east, south, and south-west. As in June stem rust is usually only present in traces or is absent in Western Canada, and there is practically no likelihood of spores coming from more eastern areas, east wind during this month is not regarded as favourable to the introduction of spores in any part of Western Canada, or during the other two months in Manitoba. In July and August, however, owing to stem-rust development in Manitoba and eastern Saskatchewan, this wind becomes a spore-bearing one for more western parts. South-west wind is probably only of importance for Manitoba and possibly eastern Saskatchewan, as wind from that direction reaching western Saskatchewan and Alberta would largely

pass over territory in which there would be usually comparatively little stem rust. For a similar reason, as mentioned earlier, south wind reaching the two latter areas is probably of little importance in introducing spores, and hence for them is not regarded as a spore-bearing wind. Exceptionally, however, south wind may become of importance as a spore-bearing wind for these two areas, for, as has already been pointed out, it is probable that in 1938 south winds brought a considerable quantity of spores to western Saskatchewan and possibly also to Alberta. At any rate, the prevalence of stem rust in these two areas in a comparatively dry year would seem to indicate that an unusually large amount of inoculum must have been present.

It is evident from Table 22, that for heavy rust years the average number of hours of wind favouring the introduction of spores at the different stations are in some instances higher, in other instances lower, than the average number for the 17-year period. For example, the number of hours of southeast wind in June is slightly higher at Winnipeg, Qu'Appelle, Scott, and Lacombe, although lower at Lethbridge, for the heavy rust years; but in July the number is higher only at Winnipeg, and in August at none of the stations. Actually, in June, or the greater part of it, southeast winds have probably little significance for Manitoba or eastern Saskatchewan as far as the importation of spores is concerned, for such winds pass largely over a territory of forest and lake, and during most of that month stem rust is largely absent from any cereal-producing areas in that direction. In this connection, it may be remarked that when spore showers occur in June, their occurrence is associated with direct south wind. With regard to the other wind directions, a similar situation generally obtains. The average number of hours of south wind in June at Winnipeg and Qu'Appelle, for the heavy rust years, is slightly higher than the respective 17-year averages for those two points, although probably not sufficiently higher to have any significance, but the average is lower for the heavy rust years at Winnipeg in the other two months, and in July at Qu'Appelle. For the same two stations, the average number of hours of southwest wind in each of the three months (excepting August for eastern Saskatchewan) is less for the heavy rust years than for the average year. Broadly speaking, the data seem to support the evidence already given that epidemic years are not characterized by an increased frequency or duration of winds favourable to the introduction of stem-rust spores, and they are in general accord with Lambert's (113) conclusion in respect to the Mississippi Valley, namely, that no association exists between years in which stem-rust epidemics occur and years in which conditions seem most favourable for spores to be blown up from the south.

FACTORS CONTRIBUTORY TO REGIONAL DIFFERENCES IN STEM-RUST SEVERITY

Reference has already been made to the fact that Manitoba and eastern Saskatchewan are invariably more severely affected by stem rust than are western Saskatchewan and Alberta (*cf.* Figure 1). In the latter region, the comparative freedom from severe stem-rust damage is not attributable to resistance in the crops, as susceptible varieties are still

almost exclusively grown. The geographical position of the two regions and the intimately related meteorological conditions seem to account satisfactorily for the marked differences in the amount of infection between the two regions. As mentioned previously, the more easterly region lies directly north of the Mississippi Valley and is directly exposed during periods of south wind to the introduction of stem-rust spores from that area, where severe outbreaks of the disease periodically occur. The more westerly region, on the other hand, lies north of a mountainous territory in which grain-growing is somewhat more limited and stem rust relatively unimportant, so that this region is less directly exposed to heavy spore invasions from the south. It should be mentioned, however, that for this more westerly region (western Saskatchewan and Alberta), an additional source of inoculum is the more easterly region (Manitoba and eastern Saskatchewan), especially in seasons when a stem rust is prevalent in the latter; but this source seldom becomes of importance until the middle of July, and in some years even later.

Winds Favouring or Opposing Spore Introduction

The advantage of the more westerly over the more easterly region in respect to freedom from stem rust is shown in the lesser number of hours of wind favourable to the introduction of rust spores. Table 23 gives the mean number of hours of wind favouring, and opposing, the introduction of spores at six stations in Western Canada for June, July, and August, from 1922 to 1938. Winnipeg may be taken to represent eastern Manitoba; Qu'Appelle, eastern Saskatchewan; Scott, western Saskatchewan; and Lethbridge, Calgary, and Edmonton, the southern, central, and northern parts of Alberta, respectively. Winds favourable to the introduction of spores in eastern Manitoba are from a southerly direction (SE., S., SW.), whereas such winds in Alberta are easterly (E., SE.); unfavourable or opposing winds in the former are northerly (NE., N., NW.), in the latter, northerly and westerly (N., NW., W., SW.). Between the sector favouring and that opposing spore introduction are two opposite sectors, referred to as varying, in which the winds may perhaps at one time favour, at another time oppose the introduction of spores.

It will be seen from Table 23 that, during the 17-year period 1922 to 1938, the mean number of hours of favouring wind per month at Winnipeg and Qu'Appelle, the two more eastern stations, are not greatly less than the mean number of hours of opposing winds. In fact, at Winnipeg, in July and August, the hours of favouring wind exceed those of opposing wind. At the stations in the more westerly region (Scott, Lethbridge, Calgary, and Edmonton), the mean number of hours of favouring wind are much less than at the two more easterly stations, and are from two to three times less than of opposing wind. Spores therefore originating, for instance, in the Upper Mississippi Valley, have not only much farther to travel to reach the more westerly region than to reach the more easterly one, but have much fewer hours of favouring wind by which to make the journey.

TABLE 23.—MEAN HOURS OF WIND PER MONTH FAVOURING OR OPPOSING THE INTRODUCTION OF WIND-BORNE SPORES FOR JUNE, JULY, AND AUGUST DURING THE 17-YEAR PERIOD 1922-1938, AT SIX STATIONS IN WESTERN CANADA, TOGETHER WITH THE MEAN HOURS OF WIND FROM OTHER DIRECTIONS

Station	Classes of wind	Mean hours per month		
		June	July	August
Winnipeg, Man.	Favouring (S.E., S., S.W.)	286.7	309.1	330.4
	Opposing (N.E., N., N.W.)	302.7	296.3	266.1
	Varying (E., W.)	127.8	132.5	144.8
Qu'Appelle, Sask.	Favouring (E., S.E., S.)	250.1	257.0	256.4
	Opposing (N., N.W., W.)	281.5	316.5	304.1
	Varying (N.E., S.W.)	179.6	161.8	176.1
Scott, Sask.	Favouring (E., S.E.)	202.3	197.4	175.1
	Opposing (N., N.W., W., S.W.)	388.3	409.1	440.9
	Varying (N.E., S.)	127.9	135.5	125.9
Lethbridge, Alta.	Favouring (E., S.E.)	121.1	128.7	119.6
	Opposing (N., N.W., W., S.W.)	469.2	460.2	467.6
	Varying (N.E., S.)	119.3	126.0	122.6
Lacombe, Alta.	Favouring (E., S.E.)	157.7	182.5	138.4
	Opposing (N., N.W., W., S.W.)	373.8	356.3	372.4
	Varying (N.E., S.)	166.3	184.7	208.7
Calgary, Alta.	Favouring (S., S.E.)	158.3	167.2	139.4
	Opposing (N., N.W., W., S.W.)	430.1	433.8	470.4
	Varying (N.E., S.)	108.0	112.1	117.0

Differences in Rainfall

With regard to rainfall in Western Canada, it has been shown that seasons of medium and heavy rust infection have a greater rainfall than seasons in which infection is light. From Table 9, it will be seen that the average rainfall for the spring and summer months in the two Manitoba divisions is greater than in the eastern Saskatchewan division (Qu'Appelle River) and still greater than in each of the two western Saskatchewan divisions and the north-central one (Saskatchewan Forks). In the Alberta divisions, however, the rainfall shows an increase over that of western Saskatchewan, the increase being largely due to the higher rainfall in the western portion of those divisions. This general trend in the rainfall of Western Canada is represented in Figure 12, which is, for the most part, an adaptation of a precipitation map issued by the Research Department of the Searle Grain Company Limited, Winnipeg, and represents the long-time average precipitation of the period April 1 to July 31 of each year combined with the average annual precipitation of the period August 1 to October 31 of the preceding year. From this figure, it will be seen that the precipitation for the months indicated is highest in southern Manitoba and in the more elevated area just east of the Rocky Mountains. The area of least precipitation spreads out on either side of the Saskatchewan-Alberta boundary. In occasional years, there may be wide deviations from the long-time average in certain areas, as happened, for example, in the South Saskatchewan River division (southwestern Saskatchewan) in 1916,

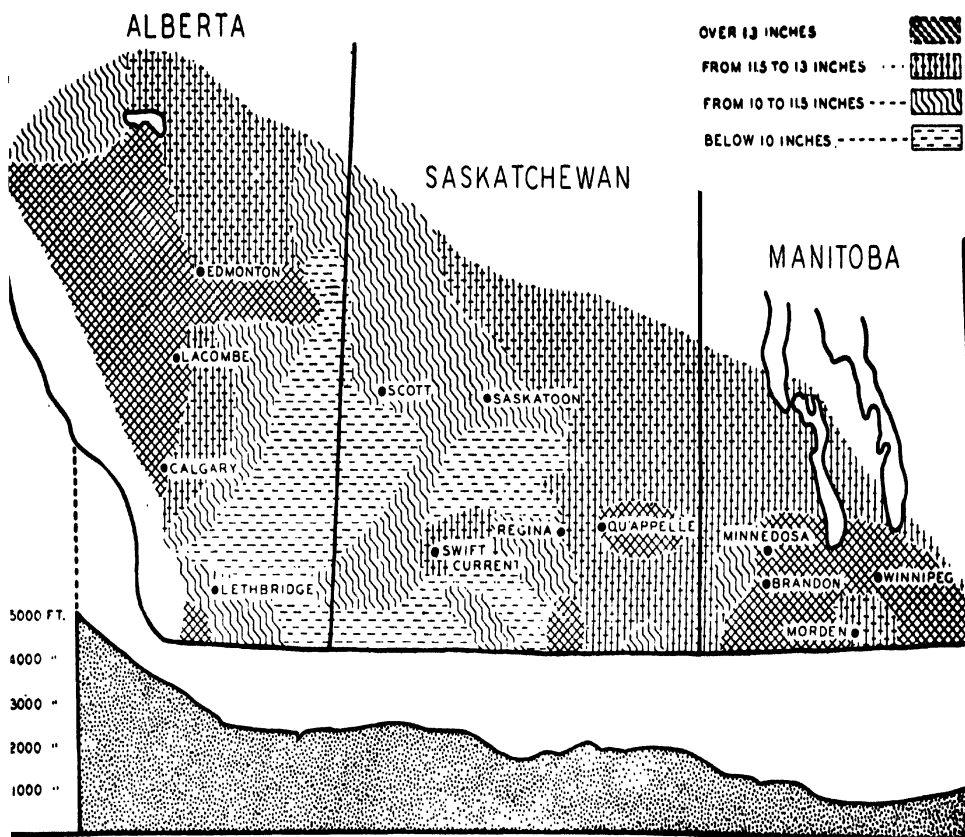


FIGURE 12. Map of Western Canada showing the average long-time precipitation (in inches) during the periods August-October of one year and April-July of the following year. The lower portion of the figure indicates the altitude (in feet) of points along a line passing through Winnipeg, Brandon, Qu'Appelle, Regina, Swift Current, and Calgary.

1923, and 1927, three epidemic years in which the spring and summer rainfall was 83, 54, and 70%, respectively, higher than the 23-year average. The lower rainfall in western Saskatchewan and eastern Alberta tends very probably to afford this more westerly region a certain amount of protection against infestations of stem rust, although in passing it may be mentioned that in this region in 1938, a year in which stem rust did considerable damage, the spring and summer rainfall was an inch or more below average. In this region, however, temperatures are lower, particularly at nights, than in the more easterly region, and for this reason the effectiveness of the moisture is somewhat greater, a circumstance which perhaps in some measure tends to compensate for the lower precipitation. Nevertheless, the fact that in four out of the five years in which stem rust was prevalent in this westerly region the rainfall was considerably above average, indicates that the lower rainfall in this region probably hinders the westward advance of the disease.

Differences in Temperature

Earlier in this paper, it was pointed out that, in the more westerly meteorological areas of Western Canada, summer temperatures are on the average lower than in the eastern divisions. Similarly, temperatures in northern districts tend to be somewhat lower than in southern districts. For instance, the mean temperature for the 3-month period, June to August, in the Red River (Manitoba) division is 65.2° F. and in the Bow River (Alberta) division it is 61.3° F., while in the North Saskatchewan (Alberta) division it is 58.7° F. The temperature, of course, decreases as the altitude increases. It will be seen from Figure 12 that the land surface rises from east to west. Winnipeg, for example, has an elevation of 772 feet and Calgary of 3,438 feet. For this western region, as already mentioned, August is the critical month in respect to stem rust. When the temperature falls below 60° F., stem-rust development is appreciably retarded, and even infection may be impeded if the fall is pronounced. For the 23-year period under review, the average temperatures for August in the five more westerly meteorological divisions are as follows: in Saskatchewan—South Saskatchewan River, 63.0°, and North Saskatchewan River, 60.3° F.; in Alberta—Bow River, 61.4°, Red Deer River, 59.1°, and North Saskatchewan River, 58.3° F. It is thus seen that the average temperature for August in three of these divisions is below 61° F., a temperature below which Stakman and Lambert (207) found that no epidemics had occurred in the Upper Mississippi Valley. In another division, it is only slightly higher. In spite, however, of the relatively cool temperature in August in this more westerly region, stem rust is prevalent in occasional years and causes some damage. Nevertheless, there is little doubt that the disease is held somewhat in check by August temperatures. The same is true of the Saskatchewan Forks division, in north-central Saskatchewan, where the average temperature for August is 61.5° F. On the other hand, it is evident from Table 15 that the seasons in which stem rust was most prevalent in these meteorological divisions were no warmer generally than the average season.

TIME OF SEEDING AND OF HARVESTING IN RELATION TO OCCURRENCE OF STEM-RUST EPIDEMICS

It is generally accepted that the time of seeding and of harvesting a crop usually has an important bearing on the amount of stem-rust infection that develops in it. Under ordinary growing conditions in any given locality, a variety of wheat or of one of the other cereals ripens within approximately the same number of days from the time it is sown. If seeding is early or late, harvesting is usually expected to be correspondingly early or late. It has long been known that crops seeded early have a better chance than those seeded late of escaping stem-rust damage. Tull (219) recognized this fact more than two centuries ago, even though he was unaware of the true nature of the disease. Following the severe outbreak of the disease in Europe in 1804, Banks (11) stressed the importance of early crop maturity in preventing rust losses. In more recent times, it has been the experience of many investigators (46, 52, 59, 94, 129, 177, 211, and others) to find that early sown crops are usually lightly affected by stem rust. The growing of early-maturing varieties, likewise tends to

prevent severe losses from the disease (5, 58, 118, 142, 189, 211). On the other hand, late sown crops frequently suffer severe rust damage, as likewise commonly do late-maturing varieties (9, 34, 46, 52, 65, 67, 69, 89, 100, 123, 128, 195). Freeman and Johnson (67) point out that the critical period for infection in any given locality is a 10-day period about heading time, and that if for any reason this period is extended, the amount of infection is increased. Peltier (157) claims that an extended fruiting period (from heading to ripening) is one of the important factors favouring the development of an epidemic. In general, it may be said that when the period of exposure to inoculum is lengthened through any cause, the danger of heavy infection developing is increased.

As has been widely recognized, the explanation of the lighter infection on early ripening crops lies largely in the fact that when the disease appears they are farther advanced toward maturity than are the later ripening crops, and hence the disease is present on them a shorter time and cannot, therefore, interfere to so great an extent with their development. Besides, as the growing season progresses, the severity of the attack tends to increase, and hence the early grain, by ripening early, escapes the maximum amount of infection. Late sown crops, on the other hand, are still green and in a susceptible condition when inoculum is present in greatest abundance, and are, therefore, exposed to the heaviest possible infestation. On account of the cooler weather prevailing in the autumn in north temperate regions, such as Western Canada, the fruiting period of late sown crops is considerably prolonged and hence their exposure to infection is still further increased.

As a means of avoiding loss from stem rust, early seeding has been recommended for many years in Western Canada. This recommendation was based on experience and was made years before the source of inoculum that initiates stem rust in this region was investigated. Observation had shown that the earliest ripening fields usually escaped serious rust injury. Why this was the case is now apparent. Wind-borne inoculum undoubtedly has always been largely responsible for the initiation of stem-rust infection in this region. When once infection was established, the multiplication of inoculum, locally, proceeded with greater or less rapidity, depending on the number of initial infections and the favourableness of weather conditions. Concurrently with this local multiplication of inoculum, ever increasing amounts of inoculum were blown in from infected areas to the south, until harvesting there was largely completed. The longer the crops remained green after infection appeared, the longer was there the opportunity for new infections to occur and the multiplication of inoculum to take place.

There is no doubt that in any particular year if the varieties grown are susceptible to stem rust, the fields to ripen earliest are the ones least damaged by the disease, nor is there doubt that a prolongation of the period between heading and ripening of the crop gives opportunity for increased infection until maximum infection is established. The question considered here is whether or not in Western Canada seasons in which seeding or harvesting, or both, were early are associated with light rust years, and those in which one or both of these operations were delayed are associated with heavy rust years; and whether or not in heavy rust years the "fruiting period" of the grain was of more than average length.

A good deal of diversity occurs from year to year in the dates on which seeding and harvesting operations usually become general in Western Canada, the dates for each of these operations being from one to two weeks or more earlier in the southern parts of this area than in the northern parts. Table 24 gives for years of light, medium, and heavy stem-rust infection between 1916 and 1938, the dates on which wheat seeding and harvesting began generally in Manitoba and in eastern Saskatchewan, excepting in the most northerly parts. The dates for Manitoba have been taken from

TABLE 24.—DATES ON WHICH SEEDING AND HARVESTING OF WHEAT BEGAN GENERALLY IN MANITOBA AND EASTERN SASKATCHEWAN IN YEARS WHEN STEM-RUST INFECTION WAS LIGHT, MEDIUM, AND HEAVY IN THOSE AREAS BETWEEN 1916 AND 1938

Light			Medium			Heavy		
Year	Seeding	Harvesting	Year	Seeding	Harvesting	Year	Seeding	Harvesting
<i>Manitoba</i>								
1917	Apr. 25	Aug. 16	1919	Apr. 25	Aug. 1	1916	May 1	Aug. 12
1918	Apr. 8	Aug. 18	1921	Apr. 28	Aug. 1	1923	May 5	Aug. 8
1920	May 3	Aug. 10	1924	May 5	Aug. 23	1927	May 5	Aug. 22
1922	Apr. 22	Aug. 5	1925	Apr. 15	Aug. 10	1935	Apr. 27	Aug. 8
1926	Apr. 14	Aug. 9	1930	Apr. 15	Aug. 5	1938	Apr. 12	July 30
1928	Apr. 25	Aug. 16	1937	Apr. 26	Aug. 4			
1929	Apr. 23	Aug. 8						
1931	Apr. 15	Aug. 5						
1932	Apr. 19	Aug. 1						
1933	Apr. 26	Aug. 1						
1934	Apr. 21	Aug. 3						
1936	Apr. 29	July 24						
Average	Apr. 22	Aug. 7		Apr. 23	Aug. 6		Apr. 28	Aug. 10

23-year average: Seeding, April 24; Harvesting, August 7

Eastern Saskatchewan

1917	May 6	Aug. 21	1919	Apr. 27	Aug. 2	1916	Apr. 24	Aug. 23
1918	Apr. 13	Aug. 19	1921	Apr. 26	Aug. 16	1923	May 4	Aug. 21
1920	May 6	Aug. 29	1925	Apr. 22	Aug. 18	1927	May 5	Aug. 29
1922	May 4	Aug. 18	1930	Apr. 18	Aug. 13	1935	Apr. 23	Aug. 11
1924	Apr. 29	Sept. 3				1938	Apr. 30	Aug. 10
1926	Apr. 19	Aug. 18						
1928	May 2	Aug. 25						
1929	Apr. 22	Aug. 17						
1931	Apr. 11	Aug. 11						
1932	Apr. 15	Aug. 11						
1933	Apr. 25	Aug. 4						
1934	Apr. 18	Aug. 12						
1936	Apr. 27	Aug. 2						
1937	Apr. 18	Aug. 3						
Average	Apr. 24	Aug. 16		Apr. 23	Aug. 12		Apr. 29	Aug. 19

23-year average: Seeding, April 25; Harvesting, August 16

Crop Bulletins published annually by the Manitoba Department of Agriculture, with the exception of those for harvesting in 1916 and 1917, which have been kindly furnished by the Experimental Farm, Brandon, Manitoba; those for Saskatchewan, from the Annual Reports of the Saskatchewan Department of Agriculture. In the areas indicated, the bulk of the wheat crop would usually be sown or harvested each year within two weeks of the respective dates given in Table 24. During the years under review, Marquis was the variety of wheat principally grown. It is quite susceptible to the races of stem rust commonly present in Western Canada, and on an average matures in 106 days in Manitoba but requires about a week longer to mature in Saskatchewan.

According to the data given in Table 24, the average date on which seeding of wheat became general in Manitoba during the 23 years under review is April 24, and for harvesting, August 7, an interval of 106 days; in Saskatchewan the date for seeding is April 25 and for harvesting, August 16, an interval of 114 days. In Manitoba, the average date in the heavy rust years for seeding is 4 days, and for harvesting 3 days later than for the whole period; thus the average length of time from seeding to harvesting in the heavy rust years is 1 day less than the 23-year average. In the light rust years, harvesting was on the same day as, and seeding 2 days earlier than for the whole period, thus making the period from seeding to harvest 2 days longer than the average for the 23 years. In other words, the average time from seeding to harvest in the heavy rust years was 3 days less than in the light rust years. In only one epidemic year (1927) did weather conditions delay markedly the maturing of the crop. In 1923, the time between seeding and harvest was surprisingly short, only 88 days. There is, however, the possibility that in the heavy rust years harvesting may have been begun slightly before the crop was fully matured, as there was a general belief among farmers that by cutting the crop "on the green side" less damage from the disease would result. This early commencement of harvesting in the heavy rust years, however, would not have probably reduced the period between seeding and harvesting by more than 2 or 3 days at most, so that ripening in the heavy rust years would likely have occurred within about the same number of days from seeding as was required in the light rust years.

As already indicated, the average time from seeding to harvest in Saskatchewan is about a week longer than in Manitoba. This difference is largely due to the somewhat higher elevation of eastern Saskatchewan, and the consequently cooler climate. On the average, seeding in the heavy rust years is 5 days later than in the light rust years, but harvesting is only 3 days later, so that actually the time between seeding and harvest in the heavy rust years is 2 days less than in the light rust years, and 1 day less than the 23-year average. Here, too, the early cutting of rusted crop may account for the shorter period between seeding and harvest in the heavy rust years. It may, therefore, be concluded that, on an average in Manitoba and eastern Saskatchewan, there was little or no difference between the heavy and the light rust years in respect to the length of time needed for the wheat crop to mature.

As seeding was 4 or 5 days later than average in the heavy rust years, it would be expected that, other things being equal, the crop in such years

would have been somewhat less advanced when stem-rust infection appeared than it was in other years, provided the infection appeared at about the average time. As shown in Table 25, the wheat crop in Manitoba was always in head or heading before stem rust became lightly prevalent in that province. In 1923, 1935, and 1938, heavy rust years, a general light infection occurred synchronously with heading in eastern Manitoba and rapidly became intensified. The same was true of 1937, a year of moderately heavy rust in most of Manitoba but of severe infection in the south-central portion. A light general infection occurred also at heading time in 1929 and 1936, two light rust years, but, in these two years, there was not a rapid subsequent increase of infection. In other years, a light general infection did not appear until several days or longer after the crop came into head, and in most of these years the intensification of the infection was less rapid than in 1923, 1935, and 1938. In these three epidemic years, the crop was undoubtedly less far advanced when infection became severe than it was in the other years, and hence heavy infection was longer present on the crop. The same observations apply in these years to western Manitoba, except that in 1938 heading was practically completed before a light general infection became prevalent. The wheat crop in this area was thus farther advanced when a light general infection developed than it was in eastern Manitoba.

Unfortunately, consideration could not be given in this discussion to the years 1916 to 1922, as the data concerning the development of the disease and of the crop in those years are not sufficiently complete to warrant their being used as a basis for deductions. For the same reason, discussion dealing with eastern Saskatchewan is omitted. There is little doubt, however, that had the data been available for study the same general pattern found for Manitoba from 1923 to 1938 would apply, namely, that in the heavy rust years the period from seeding to harvest was about of average length, that a light general infection did not occur until the crop was heading or in head, and that the light general infection passed rapidly into severe infection. It would seem, therefore, that in Western Canada, as far as the time factor is concerned in the development of stem-rust epidemics, the crux of the situation lies in the early establishment of a light general infection and its rapid transition into a heavy infection. Only in one heavy rust year, 1927, was the development of an epidemic associated with a marked prolongation of the fruiting period of the crop. As has been already pointed out, however, a prolonging of the fruiting period is undoubtedly of importance every year in the establishment of heavy infection on late crops.

CROP MATURITY IN RELATION TO EARLY INFECTION

It was mentioned earlier that infections rarely or never appear in a district of Western Canada until the crop or a considerable part of it in that district has headed or is at least in the process of heading. In some other parts of the world the appearance of stem rust in the field seems to coincide with or follow the heading of the grain crop. Peltier (157) mentions that in Nebraska, over a period of 10 years, stem rust was never found in the spring on winter wheat before the crop had reached the very late boot or early heading stage, a fact which he attributes to lack of

inoculum and to unsuitable weather conditions. Traces of it, however, do occasionally occur in late autumn on seedling plants of this crop (158). Verwoerd (223) states that in the Cape province of the Union of South Africa, no infection usually appears before the wheat is in head. According to Shitikova-Roussakova (183), infection in the Amur Region in Eastern Asia is usually first seen in the field at the time of heading and flowering of the wheat. D'Oliveira (53) states that in Portugal stem rust appears in the crop during or after heading. In Kenya, East Africa, Thorold (217) relates that stem rust does not usually appear until the crop is tillering or heading, and Dawson (50), that it nearly always appears late, generally after flowering time.

The freedom, or comparative freedom, from infection of cereals prior to heading has been attributed by some investigators to the greater resistance of the less mature plants. In a study of the relation of the time of seeding and stage of plant development to rust development, Bolley (21) sowed 8 varieties of oats at 14 different dates from April 5 and June 23 in 1895 and 1896, and concluded from his tests that all varieties were comparatively resistant to the rusts (stem rust and crown rust) until a period of their growth approaching the flowering time. Later, he (22) states that, with some varieties of wheat and oats, the tissue must attain a certain degree of maturity before it is congenial to the rust. After mentioning that soft succulent wheat stems are more open to rust attack than others, Bolley and Pritchard (24) remark that every variety is "more open to attack by rust just at the period following heading time to the point of full blossom stage." Freeman and Johnson (67) found that plants inoculated between heading and full bloom were more severely rusted than plants inoculated before or after this period. They suggest that at that stage there may be a particular physiological weakness due to rapid growth and abundant elaboration of starch that might increase the susceptibility of the grain.

As a deduction from the results of their trials of wheat varieties for rust resistance, Jenkin and Sampson (101) drew the conclusion that there appeared to be one or more periods during the maturity of the plant when it is most susceptible to rust. In a report on the behaviour of certain wheats to rust attack in the vicinity of Paris in 1923 and 1924, Foex Gaudineau, and Guyot (62) relate that Goldendrop, a winter wheat, was sown in the autumn and in the spring. At the first of August, the spring sown plots, still in the tuft stage, were surrounded with plants heavily infected with stem rust, but although some leaf-rust pustules were present in the plots, there were no stem-rust pustules. The autumn sown plots, however, bore a moderate infection of stem rust. This circumstance seemed to indicate that the stage of growth had some influence on the development of the rust. Careful observation of the development of stem rust on 1,290 pure lines of wheat, particularly on lines of Strube, led Roussakov and Pantchenko (174) to the conception of immunity in time, in contradistinction to absolute immunity, that is to say, immunity only until the setting in of a certain stage in the development of the host plant, the stage in some lines being that of ear formation, in others the milk stage, and in still others the last few days of vegetation. Levine (118) states that, although his results might be open to a different interpretation,

there seems to be "sufficient observational evidence to indicate that the susceptibility of plants does depend to a considerable extent on their stage of development. They seem to be quite susceptible in the seedling stage and again at about the heading-out stage. In the jointing stage the plants show more resistance."

Gassner (71, 72, 74) concluded from his experiments in South America and Germany that wheat plants when young (up to the heading stage) are more resistant to stem rust than when older, although resistance again appears just prior to ripening. This view seems to be held by Cornelli (42) who states that, near Perugia, Italy, a strip of Mentana wheat growing between two strips of the Gentil rosso variety was attacked by stem rust while the latter variety showed no indication of infection. He points out that the Mentana variety is earlier but more rust resistant than the Gentil rosso variety, and he attributes the occurrence on the former and its absence on the latter (the more susceptible variety) to a difference in plant maturity. From experiments in 1927 and 1928 on the effect of the date of seeding on the amount of rust infection, Brega (26) found that early sowing appeared to conduce to early infection, that is to say, infection appeared earliest on the earliest sown plots (these being presumably the farthest advanced in degree of maturity).

On the other hand, Stakman and Piemeisel (212) found that cereals are usually susceptible at any age up to ripening time, and Stakman and Levine (208), that oat seedlings up to 35 days of age are quite susceptible. Peltier (156) states that in his experience susceptibility to stem rust was greater in the seedling stage of cereals than in later stages of growth. Goulden, Newton, and Brown (78) proved that certain wheat varieties that are susceptible in the seedling stage become highly resistant after heading, that is to say, they become resistant with age. Newton and Brown (147) have shown that, in wheat varieties possessing mature-plant resistance, the younger tissue is susceptible to stem rust while the older tissue of the same plants is resistant. Hart and Forbes (82) state that wheat plants in southern Minnesota have been observed badly rusted in all stages of growth prior to heading of the plants. Lambert (113) points out that, in the spring wheat area (Upper Mississippi Valley), stem rust spreads from barberry to grasses and grains during the last two weeks of May. As at that time of year, spring wheat in that region is not yet in head, the infection must occur on plants in younger stages of development. Furthermore, stem rust usually overwinters on autumn sown crops. It is also a well-known fact that susceptible cereal plants can be successfully inoculated at all stages of growth between emergence and maturity. In experimental plots at Winnipeg, a limited amount of infection has appeared almost every year on susceptible varieties of wheat as a result of artificial inoculation—the distribution of inoculum produced under greenhouse conditions—before such varieties came into head. There seems to be no doubt, therefore, that crops in pre-heading stages may become infected to a greater or less extent by stem rust.

TIME OF HEADING IN RELATION TO EARLY RUST APPEARANCE

The question, therefore, arises as to what extent, if any, the appearance of field infections in Western Canada is dependent on the stage of crop

maturity. Table 25 gives for eastern and western Manitoba the dates on which heading of wheat became general each year from 1923 to 1938, together with the dates on which stem-rust infections were first detected in the field and the dates on which a light general primary infection appeared. The dates given for heading becoming general and for the appearance of a light general infection represent, respectively, the periods in which the bulk of the wheat crop in southern and central Manitoba came into head and in which approximately 1% of the plants bore a trace of primary infection. Data relative to the other two provinces, Saskatchewan and Alberta, are not included in this table owing to their incompleteness, but the data that are available for these two provinces are entirely in agreement with the observations made in Manitoba, namely, that stem-rust infections appear on crops at or after heading.

TABLE 25.—DATES ON WHICH HEADING OF WHEAT BECAME GENERAL, ON WHICH STEM-RUST INFECTIONS WERE FIRST DETECTED, AND ON WHICH A LIGHT PRIMARY INFECTION BECAME GENERAL IN EASTERN AND WESTERN MANITOBA FROM 1923 TO 1938

	Eastern Manitoba			Western Manitoba		
	Heading of wheat	Earliest stem-rust infection	Appearance of light general infection	Heading of wheat	Earliest stem-rust infection	Appearance of light general infection
1923	July 3-10	July 5	July 5-12	July 4-11	July 6	July 8-15
1924	July 12-19	July 7	July 12-19	July 14-21	July 18	July 18-25
1925	July 7-14	June 23	July 10-17	July 9-16	July 12	July 13-20
1926	July 3-10	July 2	July 8-15	June 28-July 5	July 16	July 18-25
1927*	July 8-20	July 6†	July 12-19	July 4-11	July 15	July 17-24
1928	July 7-14	July 9	July 20-27	July 3-10	July 20	July 23-30
1929	July 3-10	July 3	July 3-10	July 5-12	July 3	July 4-11
1930	July 2-9	June 26	July 6-13	July 1-8	July 5	July 9-16
1931	June 29-July 6	July 5	July 7-14	July 1-8	July 12	July 18-25
1932	June 20-27	June 20	July 1-8	June 19-26	July 7	July 10-17
1933	June 28-July 5	June 28	July 10-17	June 25-July 2	July 14	July 15-22
1934	July 5-12	July 5	July 9-16	July 1-8	July 15	July 16-27
1935	July 5-12	July 2	July 3-10	July 4-11	July 3	July 3-10
1936	June 27-July 4	June 26	June 27-July 4	June 30-July 7	July 1	July 1-8
1937	July 5-12	July 1	July 6-13	June 28-July 5	June 28	June 29-July 6
1938	June 26-July 3	June 22	June 27-July 4	June 22-29	June 22	June 28-July 5

* An unusually wet growing season caused marked variation in the stage of crop maturity from field to field, hence the period of heading was unduly prolonged.

† Infection first appeared on winter wheat plots at Winnipeg.

A comparison of the dates on which heading of wheat became general and on which a light general infection appeared in eastern Manitoba, shows that in several years—1923, 1924, 1929, 1935, 1936, 1937, and 1938—the dates were synchronous or nearly so. In all of the other years, the heading of wheat preceded, by a few days to a week or more, the appearance of a light general infection. Only in 1935 did a light general infection appear before heading was well underway. In this year infections began to appear in many fields on the uppermost leaves when the heads were only partly emerged from the sheaths. Infections on the stems began to appear 3 or 4 days later. In western Manitoba, there is close agreement of dates

in 1929, 1935, 1936, and 1937, but in the other years, heading of wheat always preceded the appearance of a light general infection by a less or great number of days. It may, therefore, be said that in every year wheat in Manitoba had headed or was heading by the time scattered primary infections appeared in this crop. This fact does not necessarily indicate that the date of heading influenced the time when a light infection became general. Indeed, the variation in the length of interval between the time of heading and of light general infection from year to year would indicate that some other factor or factors determined the time that light infection became general. As a matter of fact, the only years in which the appearance of a light general infection could have been delayed by the maturity of the crop would be those years in which light general infection synchronized with the heading of the crop, as obviously, after the crop had headed, immaturity of the crop could not be held responsible for any delay thereafter in the appearance of the rust. Consideration may, therefore, be given to those years in which the appearance of a light general infection synchronized with the heading of the crop, in order to ascertain to what extent in these years the time that a light infection became general was influenced by the arrival of inoculum and by weather conditions.

TIME OF APPEARANCE OF A LIGHT GENERAL INFECTION IN RELATION TO
ARRIVAL OF INOCULUM AND TO WEATHER CONDITION
PRIOR TO HEADING OF CROP

Between 1923 and 1938, as mentioned above, the appearance of a light general infection synchronized with the heading of the wheat crop in 1923, 1924, 1929, 1935, 1936, 1937, and 1938. Of these seven years, two, 1923 and 1924, must be excluded from consideration, as, for them, data relating to the time of arrival and the amount of inoculum are lacking. In 1935, practically no spores were detected in the atmosphere before June 23, but a heavy spore shower occurred on June 24 and 25. Rain fell on June 24, 25, and 26, amounting to 0.56 inches, a trace, and 0.18 inches, respectively. Much infection undoubtedly occurred at this time. Between June 24 and July 5, the average daily temperature was 69.1°F. , with an average daily maximum of 76.9° and average daily minimum of 61.3°F. Infections began to appear at Winnipeg on July 2, and by July 5 a light general infection was beginning to become established, which increased unusually rapidly to a moderately heavy infection by July 12. With such temperature conditions from June 24 to July 5, the time required for a light general infection to appear—if, as supposed, much infection occurred on June 24, 25 and 26—seems rather long (10 to 12 days), but probably not unduly long in view of the persistent heavy cloudiness prevailing during much of that period. Stakman and Piemeisel (212) claim that in cloudy weather the incubation period may be prolonged by a week. The more extended but lighter spore showers, from June 28 to July 5, apparently were responsible for the very rapid transition from light to moderately heavy infection. There is probably, therefore, little ground for supposing that in this year the time of rust appearance was influenced by the developmental stage of the crop.

To provide a basis for a discussion with respect to the remaining four years, data on weather conditions and the time of arrival and the relative numbers of urediospores present in the air are given in Table 26 for a period of 18 days prior to the appearance of a light general infection on wheat in the fields of eastern Manitoba. The probability of dew formation at night was arrived at by consultation of Smithsonian Meteorological Tables, mentioned in connection with the discussion of dew in relation to outbreaks of stem rust. Sufficient data are presented to indicate fairly clearly the kind of weather that prevailed during the period involved in each of the four years.

In 1929, a heavy spore shower occurred on June 16 and 17, the number of spores intercepted by the slides exposed at Winnipeg being 133 and 193, respectively. Rain fell on June 17 and probably there was deposition of dew on the preceding night. No more spores, except one on June 27, were detected by the slides until July 3, the day on which the first pustules appeared and a light general infection began to develop. During the interval from June 17 to July 3, the mean temperature was 62.3°, the mean daily maximum 73.6°, the mean daily minimum 52.1° F., the range being from 87° to 41° F. The weather was generally cloudy and damp with a trace or more of rain on 11 of the 17 days. On the supposition that infections occurred on June 16 and 17, a period of 16 days was, therefore, required for the development of the earliest appearing pustules. The question, therefore, to be decided is whether or not, under the temperature and light conditions that prevailed, the organism actually required that length of time for pustule development.

To this question perhaps no categorical answer can be given, but some indication of the length of time required may be gained from greenhouse experiments in which the temperature fluctuated within a more or less comparable range. For instance, Newton and Johnson⁹ found that, in greenhouse experiments, inoculations made on wheat seedlings on April 28 resulted in full pustule development by May 16, a period of 18 days, during which the mean temperature was 62.6°, the mean daily maximum 74.5°, the mean daily minimum 51.2°, and the range from 85° to 42° F. While this experiment, and the ones mentioned later were in progress, the weather at Winnipeg was generally cloudy, a condition that tended to retard rust development. In view of the very considerable cloudiness from June 17 to July 3, 1929, there is a good possibility that stem rust would have required upwards of 16 days for development.

In 1936, the first definite spore shower occurred on June 12 and 13, and the first pustules appeared in the field on June 26. This spore shower was light in comparison with those of 1929 and 1935. Some infection may have occurred on June 12, 13, and 14, although conditions were perhaps not very favourable for that process. A trace of rain fell on the first two days, but, probably owing to the wind velocity, the plants soon dried and no dew was deposited at night. Dew probably was present in the third night, but the low temperature (min. 43° F.) likely inhibited any considerable amount of infection. On June 15 and 16, however, there was rain and the

⁹ Unpublished data of Dr. Margaret Newton and Dr. Thorvaldur Johnson, Dominion Laboratory of Plant Pathology, Winnipeg, Manitoba.

sky was completely overcast, so that it is probable infection occurred on these days, particularly during the daylight hours of June 15. No further spores were detected until June 25 and no more rain fell until June 26, although dew likely occurred on several nights of this interval. There is a strong probability that the rust pustules that appeared on June 27 rose from infections that occurred on or before June 16, twelve days or more earlier. During this interval the mean temperature was 62.9° F., the mean maximum temperature was 74.8°, the mean minimum temperature 51.1°, the range being from 92° to 40° F. These temperatures coincide moderately well with those given for the greenhouse experiment mentioned above in connection with the incubation period of stem rust in 1929, although the range is 6° F. wider. As there was less cloudiness during the period involved in 1936 than in 1929, a shorter incubation period for the rust would be expected, but probably not much shorter than that which was actually required. Were it not for the comparatively high temperatures that prevailed during the last three or four days of the period, the incubation period would probably have been somewhat longer.

In 1937, a trace of spores—mostly 1 per day, 11 in all—was detected by the slides exposed from June 10 to 18. Light rain fell on June 13, 16, and 18, and the possibility that dew occurred on all but one night seems to have been good. Unless the spores present were non-viable, it would be expected that some of them would cause infection, as the mean temperature from June 13 to 18 was 68.7° F., the temperature range being 51° to 84° F. It seems likely that infections occurring at this time were responsible for the pustules that began to appear on July 1, about two weeks later. As shown in Table 26, some spores were present on June 19 and a light spore shower occurred from June 21 to 24. Rain fell on June 19, 22, and 23, and dew was probably present at night from June 20 to 23. The likelihood is that a moderate amount of infection occurred at this time. From then until a light general infection began to appear, a period of about two weeks, relatively few spores were present in the air, the sky was moderately clear, rain fell only once, and dew seems to have been absent or light on five nights. It would, therefore, seem that the increase of stem rust after July 6 can be traced fairly directly to infections that occurred prior to June 23. From June 19 to July 6, the mean temperature was 69.5° F., with a mean daily maximum of 83.2° and a mean daily minimum of 55.9° F. the range being from 92° to 46° F. In a greenhouse experiment¹⁰, in which inoculations of seedling wheat plants were made on April 29, full pustule development was attained on May 15, after an interval of 16 days. During this interval, the mean temperature was 69.3° F., the mean daily maximum 74.7°, the mean daily minimum 55.3°, the range being from 86° to 52° F., but, as mentioned before, the weather was rather cloudy. In comparison with the temperature conditions in the greenhouse, the extremes in the field for the period discussed are considerably greater and probably tended to delay rust development as much as the slightly higher mean daily maximum tended to hasten it. Apparently, therefore, in 1937, stem rust pustules appeared in the field as early as weather conditions would permit.

¹⁰ See footnote number 9 on page 370.

TABLE 26.—DATA RELATIVE TO THE OCCURRENCE OF STEM-RUST UREDIOSPORES AND WEATHER CONDITIONS EACH DAY AT WINNIPEG DURING A PERIOD OF 18 DAYS IMMEDIATELY PRECEDING THE APPEARANCE OF A LIGHT GENERAL INFECTION IN EASTERN MANITOBA IN 1929, 1936, 1934, AND 1938. NUMBER OF SPORES INTERCEPTED PER 1 SQUARE INCH GLASS-SLIDE SURFACE, PER CENT CLOUDINESS, RAINFALL IN INCHES, MAXIMUM AND MINIMUM TEMPERATURE (FAHR.), TEMPERATURE, RELATIVE HUMIDITY, AND WIND VELOCITY AT 7.00 P.M., AND THE DAYS (INDICATED BY +) ON WHICH THE RELATIVE HUMIDITY AT 7.00 P.M. AND THE DIFFERENCE BETWEEN THE TEMPERATURE AT 7.00 P.M. AND THE MINIMUM TEMPERATURE WERE SUCH AS TO INDICATE THAT THE AIR HUMIDITY REACHED THE DEW POINT DURING THE NIGHT

Factors	June 1929										July 1929							
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	1	2	3
Number of spores	133	193	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2
Cloudiness (per cent)	16	66	53	66	60	33	56	66	80	63	53	80	53	20	40	60	46	30
Rainfall (inches)	—	0.32	—	0.04	0.04	0.19	T	—	T	0.06	—	0.28	—	0.10	0.24	T	—	—
Temperature, maximum	94	87	81	72	76	76	65	62	68	67	72	69	74	78	78	70	76	80
Temperature, 7.00 p.m.	90	83	77	60	66	66	64	59	63	62	68	64	69	75	72	65	74	76
Temperature, minimum	62	74	57	54	53	50	46	48	48	50	41	56	50	57	54	50	47	52
Relative humidity, 7.00 p.m.	51	70	36	87	55	60	46	59	63	62	52	75	49	43	60	48	43	48
Wind velocity, 7.00 p.m.	16	25	16	8	10	13	12	9	10	12	5	12	8	14	12	10	5	20
Air dew point reached	+	—	—	+	+	+	+	—	+	—	+	+	—	—	+	—	+	+

June 1936																	
10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
0	0	2	10	0	0	1	0	0	0	0	0	0	0	0	4	0	0
85	10	80	55	T	—	100	30	53	0	26	16	30	0	33	16	26	T
T	0.05	T	T	—	0.29	0.49	—	—	—	—	—	—	—	—	—	0.14	—
74	78	88	83	60	71	54	69	76	73	73	70	78	85	92	80	82	76
65	77	84	73	58	65	53	66	73	63	66	70	73	83	84	75	81	71
43	44	61	65	43	45	52	50	49	48	40	40	40	49	60	67	58	60
50	46	45	38	58	51	97	49	50	48	59	36	52	39	50	61	49	42
7	14	18	29	6	12	8	7	14	19	9	2	6	8	6	13	6	11
+	+	—	—	+	+	+	—	+	—	+	+	+	+	+	—	+	—

Number of spores	0	0	2	10	0	0	1	0	0	0	0	0	0	0	4	0	0
Cloudiness (per cent)	85	10	80	55	T	—	100	30	53	0	26	16	30	33	16	26	T
Rainfall (inches)	T	0.05	T	T	—	0.29	0.49	—	—	—	—	—	—	—	—	0.14	—
Temperature, maximum	74	78	88	83	60	71	54	69	76	73	70	78	85	92	80	82	76
Temperature, 7.00 p.m.	65	77	84	73	58	65	53	66	73	63	66	70	73	83	84	75	81
Temperature, minimum	43	44	61	65	43	45	52	50	49	48	40	40	49	60	67	58	60
Relative humidity, 7.00 p.m.	50	46	45	38	58	51	97	49	50	48	59	36	52	39	50	61	49
Wind velocity, 7.00 p.m.	7	14	18	29	6	12	8	7	14	19	9	2	6	8	6	13	6
Air dew point reached	+	+	—	—	+	+	+	—	+	—	+	+	+	+	—	+	—

TABLE 26.—DATA RELATIVE TO THE OCCURRENCE OF STEM-RUST UREDIOSPORES AND WEATHER CONDITIONS EACH DAY AT WINNIPEG DURING A PERIOD OF 18 DAYS IMMEDIATELY PRECEDING THE APPEARANCE OF A LIGHT GENERAL INFECTION IN EASTERN MANITOBA IN 1929, 1936, 1937, AND 1938. NUMBER OF SPORES INTERCEPTED PER 1 SQUARE INCH GLASS-SLIDE SURFACE, PER CENT CLOUDINESS, RAINFALL IN INCHES, MAXIMUM AND MINIMUM TEMPERATURE (FAHR.), TEMPERATURE, RELATIVE HUMIDITY, AND WIND VELOCITY AT 7.00 P.M., AND THE DAYS (INDICATED BY +) ON WHICH THE RELATIVE HUMIDITY AT 7.00 P.M. AND THE DIFFERENCE BETWEEN THE TEMPERATURE AT 7.00 P.M. AND THE MINIMUM TEMPERATURE WERE SUCH AS TO INDICATE THAT THE AIR HUMIDITY REACHED THE DEW POINT DURING THE NIGHT—*Concluded*

Factors	June 1937										July 1937									
	19	20	21	22	23	24	25	26	27	28	29	30	1	2	3	4	5	6		
Number of spores	2	0	3	5	4	9	0	2	0	1	0	0	0	0	0	0	10	180		
Cloudiness (per cent)	43	36	T	77	37	33	17	10	43	27	40	20	47	47	57	—	27	30		
Rainfall (inches)	0 16	—	—	0.15	0.16	—	—	—	—	—	—	—	—	—	0.24	—	—	—		
Temperature, maximum	77	84	76	87	90	80	80	78	83	69	76	82	88	80	85	84	92	87		
Temperature, 7.00 p.m.	76	76	76	71	88	75	76	76	72	67	73	80	86	76	79	82	90	79		
Temperature, minimum	60	51	53	55	65	62	55	49	57	47	47	46	54	64	58	52	59	73		
Relative humidity, 7.00 p.m.	54	45	46	84	66	37	41	34	54	44	45	31	48	72	66	42	38	47		
Wind velocity, 7.00 p.m.	16	8	9	9	8	21	20	13	11	10	7	5	12	11	19	5	22	10		
Air dew point reached	—	+	+	+	+	—	—	—	—	—	+	+	+	+	+	+	+	—		
June 1938																				
Number of spores*	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27		
Cloudiness (per cent)	1	—	0	—	5	—	0	—	0	—	—	—	10	—	0	—	—	—		
Rainfall (inches)	70	46	T	86	100	100	70	—	—	—	18	56	50	—	80	20	37	80		
Temperature, maximum	61	65	78	81	63	56	69	78	85	87	91	93	82	82	70	72	74	78		
Temperature, 7.00 p.m.	52	37	38	56	52	45	52	46	52	65	82	87	77	73	69	67	72	76		
Temperature, minimum	60	48	34	76	84	74	58	43	52	90	72	45	37	41	38	52	38	55		
Relative humidity, 7.00 p.m.	6	7	9	16	17	10	3	12	13	10	8	14	8	9	14	46	37	42		
Wind velocity, 7.00 p.m.	—	+	+	+	—	+	+	+	+	+	+	+	+	+	—	—	4	7		
Air dew point reached	—	+	+	+	—	+	+	+	+	+	+	+	+	+	—	—	+	—		

* In 1938, each slide was exposed for a 2-day period.

In 1938, stem rust first appeared on June 22 and a light general infection began to appear on June 27. It is not probable that the spores present from June 19 to 22 were responsible for these infections as the intervening period was too short to permit full stem-rust development, although they undoubtedly were responsible for later appearing infections. The light general infection is probably traceable to spores present on June 13 and 14, although the earliest pustules, appearing on June 22, perhaps arose from spores present on June 9 and 10. Rain fell on June 13, 14, and 15, and as these three days were cloudy and dew was probably present at night on June 13 and 15, infection probably occurred during this time. On this supposition, an interval of 13 to 15 days was required for rust development. From June 13 to 27, the mean daily temperature was 65.7°, the mean daily maximum temperature 77.1°, the mean daily minimum 54.3°, the range being 93° to 38° F. In a greenhouse experiment¹¹, inoculations made on April 24 gave rise to fully developed pustules 17 days later. The average temperature for the period was 65.5° F., the mean daily maximum temperature 73.8, the mean daily minimum 54.1°, the range being from 87° to 46° F. Daylight hours were less per day and there was perhaps more cloudiness during this period than during that from June 13 to 27, 1938, so that it is not unreasonable to suppose that, under the weather conditions that prevailed during the latter period, rust development in the field would have required from 13 to 15 days.

In view of the comparisons given above, it is probable that, under the conditions that prevailed in the field during June and early July, stem-rust development proceeded as rapidly as could be expected. As far, therefore, as the evidence for these four or five years is concerned, there seems to be little ground to support the supposition that the stage of crop maturity had any significant influence on the time that the rust appeared in the crop.

AMOUNT OF INOCULUM AND TIME OF ARRIVAL IN RELATION TO SEVERITY OF STEM-RUST OUTBREAKS

A stem-rust epidemic arises as the result of many infections on all or the majority of the plants of one or more cereal crops. As each infection is caused by a separate spore, a great many spores are involved in producing the infections. Besides, a great many spores fall to the ground or lodge on non-susceptible plants, so that a much greater number is produced than ever succeeds in infecting cereal crops. An abundance of inoculum is, therefore, a prerequisite of a stem-rust epidemic. Freeman and Johnson (67) point out that if spores are unusually abundant in early summer, the first infections may be heavy and widespread and the chances for an epidemic may be thereby increased. Stakman (189, 193, 195) emphasizes this point in connection with the early spread of spores from infected barberry. Pekar (156, 157) claims that an abundance of initial inoculum is one of the principal factors involved in the development of epidemics in Nebraska. Levine (118) states that only abundant inoculum early in the season is conducive to heavy rust attacks. Stakman (195), in his analysis of the conditions that must exist to permit stem rust to spread from the southern to the northern part of the Mississippi Valley, implies the production of immense numbers of spores in the southern part of that area.

¹¹ See footnote number 9 on page 370.

As under favourable conditions of temperature, an infection requires approximately a week to produce spores, it is evident that if the initial inoculum is limited the time required for stem rust to reach epidemic proportions in any given area will be considerably longer, other things being equal, than if the initial inoculum is abundant. If to the initial inoculum there is added from time to time increments of wind-borne spores, the time necessary for the development of epidemic conditions will be shortened, and the greater and more frequent the increments, the shorter will be the time needed to attain such conditions.

RELATION IN WESTERN CANADA IN DIFFERENT CLASSES OF YEARS

In the different parts of Western Canada, for example, in Manitoba or eastern Saskatchewan, the period during which stem-rust inoculum is produced locally is relatively short, and on this account the multiplication of inoculum must be somewhat restricted. The average date for harvesting of wheat to become general in Manitoba is August 7 and in eastern Saskatchewan, August 16. Light general primary infection rarely is present in Manitoba until the first or second week in July, and in eastern Saskatchewan, usually from a few days to a week or more later than in Manitoba. As a rule there is then in these two areas—the most seriously affected ones—only a period of approximately a month in which the stem-rust organism has opportunity widely and intensively to multiply. The organism requires about one week to produce a new generation of spores, consequently, in these two areas, four generations of spores are about all that can be produced in most seasons before the bulk of the wheat crop is too far advanced for much infection to take place. It would appear, therefore, that as a rule stem rust could scarcely reach epidemic proportions unless the initial inoculum arrived moderately early and in considerable abundance, and increments of additional inoculum arrived subsequently from time to time.

Light Rust Years

This conclusion, at any rate, would seem to be supported by the spore-trapping data given in Table 2. It is evident from this table that in the light rust years (1926, 1928, 1931, 1932, 1933, and 1934), the amount of wind-borne inoculum in the last half of June and the first two weeks of July was relatively small. The same is true of 1936, although for economy of space the data are omitted. Because of the pronounced spore shower at the middle of June, the year 1929 is a partial exception to the general rule. However, following that shower and up to July 10, the spore content of the air was low, and continued low except in the northern part of the Red River Valley (represented by Winnipeg), where a moderately heavy infection developed on wheat. Without doubt, lack of inoculum in 1928 was the only factor that prevented an epidemic from developing in that year, as weather and crop conditions appeared to be ideal throughout the

season for stem-rust development. In 1931, weather conditions during the last week of June and the first two weeks of July were very favourable for stem-rust development in Manitoba, particularly in the Red River Valley, although cereal crops were not so dense and tall as in 1928, and after July 20 hot weather hastened the ripening of cereals, but if an abundance of initial inoculum had been present there is no doubt that very serious damage from the disease would have resulted. In the other light rust years, weather or crop conditions were probably less favourable to the development of the disease than in the two years just referred to, but even in these years the likelihood is that, at least in areas where drought was not severe, the lightness of the infection was due more to a lack of early inoculum than to the unfavourableness of weather and crop conditions.

Medium Rust Years

Only data for two medium rust years (1930 and 1937) are given in Table 2. As far as stem-rust development in these years is concerned, the chief characteristic was that epidemic conditions were somewhat late in becoming established, and consequently the earlier sown crops escaped with slight to moderate damage. It will be observed in this table that spores in the atmosphere were relatively few in both years during the latter half of June, and in 1930 continued to be few up to July 10, although only to July 4 in 1937. A similar circumstance obtained in 1925, a medium rust year, in which heavy spore showers occurred around the middle of July and later. In these years, weather and crop conditions (in 1937, only in Manitoba) were favourable to the development of stem rust. Moderately heavy infection (30 to 50% on most plants) in the field appeared in 1925 during the last few days of July and early August, in 1930 during the fourth week of July, and in 1937 during the third week of July. The delayed appearance of moderate infection in the field seems, therefore, to be definitely related to the late arrival of inoculum in considerable abundance. When a moderately heavy infection becomes established, sufficient spores are perhaps produced locally to ensure the development of maximum infection on those crops that require two or three weeks more to mature, but increments of inoculum from outside make that result more certain of being attained.

Heavy Rust Years

In contrast to the comparatively late arrival of inoculum in considerable quantity in the medium rust years, it is evident from Table 2 that at least in two of the epidemic years (1935 and 1938) inoculum was plentiful in the last week of June in one, and during the last half of June in the other; especially in the Red River Valley (represented by Morden and Winnipeg). A light general infection developed in Manitoba in 1935 by July 10 (in the southern part of the province by July 6) and in 1938 by July 5. Actually, in 1935, infection was becoming heavy by July 16, so that from July 2 and 3 when infection first appeared, there was a continuous and rapid increase

in the amount of infection. In 1938, moderately heavy infection was not established until about July 16 and heavy infection by July 25. It would appear that in the latter year the great increase of inoculum from July 9 onward was responsible for the rapid increase of infection after the middle of July. In the third heavy rust year (1927), inoculum during the last half of June and the first half of July was not particularly plentiful. Stem-rust development was slow. A light general infection was present by July 18, after which there was little change until about the last of July, when the number of infections showed considerable increase. Inoculum became abundant in late July, but owing to comparatively cool weather heavy infection did not develop until after the middle of August. This extended period of rust development was made possible by the exceptionally slow rate at which the crop matured in that year. Had the crop ripened about the average time, no epidemic would have developed.

There is a rather close relation in all these years, except 1929, between the time the inoculum—much of which must have been introduced—became plentiful and the time of rapid increase in the amount of infection. A sudden increase in the amount of infection occurred in most years with marked regularity about a week after inoculum was abundant, a fact which indicates that in most years weather conditions were at least tolerably favourable for infection during a shorter or longer period following the arrival of inoculum. There can be no doubt that the amount of wind-borne inoculum and the time of its arrival are very intimately related to the severity of the infection present on the crop at maturity.

Years 1919 and 1920

The years 1919 and 1920 are probably not exceptions to this general rule. In both years, stem rust was epidemic in the Upper Mississippi Valley (113, 207), and consequently it would be expected that inoculum in considerable abundance would have been blown northward in those years. In Western Canada, however, the records available indicate that the outbreak in 1919 was considerably less severe than in 1916 (one of the worst rust years), and in 1920 somewhat less than in 1919. On this account, 1919 has been classed as a medium rust year and 1920 as a light rust year. As mentioned earlier in this connection, it might have been just as nearly accurate to have classed the former as a heavy rust year and the latter as a medium rust year.

In Manitoba and eastern Saskatchewan, crop conditions in the spring of 1919 were good, but the weather became exceptionally warm in June, being at different stations from 4° to 7° F. above average in Manitoba and from 6° to 10° F. above in eastern Saskatchewan. During July, the temperature continued high, being from 2° to 6° F. above average in both areas, and rainfall was below normal except in eastern Manitoba, where infection became very severe. In western Manitoba and eastern Saskatchewan, heat was reported to have done about as much damage as the rust.

In 1920, the June rainfall was less than average in eastern Manitoba, about average in Western Manitoba, and considerably below average in eastern Saskatchewan, while the temperature was slightly above average in eastern Manitoba but about average in the other two areas. Throughout Manitoba, temperatures in July were from 1° to 4° F. above average and the rainfall, except at two or three points, was very considerably below average; while in eastern Saskatchewan the temperature ranged from 1° to 7° F. above average, with rainfall at some points somewhat above, but at most points below average. Generally speaking, the season was characterized by heat and drought. Nevertheless, stem rust was prevalent, being more abundant than could well have been expected under the conditions.

It is evident that in these two seasons weather conditions were not favourable for rust development, excepting in 1919 in eastern Manitoba where, as a matter of fact, stem rust was severe. Judged by the weather conditions that prevailed, infection should have been extremely light (apart from the exception just mentioned). In spite of these conditions, stem-rust infection in 1919 approached, if it did not reach, epidemic proportions, and in 1920 it was surprisingly heavy for the conditions that prevailed. In both seasons the crop ripened unduly early. It would seem that only in the presence of abundant wind-borne inoculum was it possible for such an amount of infection to develop as did develop in these two years.

Cool Seasons

Heavy stem-rust infection can develop under moderately cool conditions, and some evidence of this fact has been obtained in the present investigation. It would probably be more correct to say that the disease develops in spite of the cool weather. Such weather not only retards rust development but also the development of the host plants, so that the plants remain longer green and thus the organism is given a longer period in which to develop and spread. Apparently one of the conditions necessary for the occurrence of heavy infection under cool conditions is the presence of an abundance of wind-borne inoculum to cause mass infection. Under cool conditions, rust development probably proceeds too slowly to permit locally produced inoculum to be a factor of much consequence, although such inoculum may, in turn, become wind-borne inoculum and of consequence for some other area. For example, in spite of the cool weather in 1904, rather severe infection developed in Manitoba and eastern Saskatchewan, undoubtedly as a result of a destructive and widespread outbreak in the Upper Mississippi Valley, and this condition in the latter area was undoubtedly largely brought about by wind-borne inoculum from farther south where temperatures were more favourable for stem-rust development.

INTERRELATION OF SOME FACTORS AFFECTING STEM-RUST DEVELOPMENT IN WESTERN CANADA

In the foregoing sections of this paper, an attempt has been made to discuss separately various factors in their relation to the development of

stem rust in Western Canada. It has been shown that primary infection is almost exclusively initiated, if in recent years not entirely, by wind-borne inoculum, and that during June and the first three weeks of July such inoculum is almost invariably most abundant during periods of south wind. Considerable agreement is found year by year in the intensity of infection in the Upper Mississippi Valley and Western Canada, and also in the relative prevalence of the more commonly occurring physiologic races in these two areas. Most years of heavy stem-rust infection are associated with years in which spring and summer rainfall, as well as July temperatures, are somewhat above the average. From late June to early August, minimum temperatures tend to be higher in the heavy rust years than in the light rust years. In most of the light rust years, the rainfall for the spring and summer is slightly below average. Infection is almost invariably more abundant in Manitoba and eastern Saskatchewan than in western Saskatchewan and Alberta.

Such relationships are not fortuitous, but are the expression of a closely interrelated sequence of events. The prevalence of spores during periods of south wind arises from the fact that cereal crops mature earlier, and stem rust develops earlier, in the Upper Mississippi Valley than in Western Canada. South winds sweeping over rusted grain in the former area carry spores northward into the latter area. Consequently, the physiologic races prevalent in the one would be expected to be the prevalent races in the other. A severe outbreak of stem rust in the Upper Mississippi Valley provides an abundance of inoculum for distribution northward in Western Canada, and hence increases the chances of a severe outbreak in that area. Moreover, both areas have largely the same source of moisture—warm moist air from the Gulf of Mexico and the Caribbean Sea, brought northward by south winds. There is, therefore, a tendency year by year for moisture conditions in the two areas to be similar. For the growing season, temperatures, too, are not markedly different, although in the Upper Mississippi Valley, the season is somewhat earlier than in Western Canada. The expectation, therefore, would be to find a good deal of agreement year by year in the intensity of infection in the two regions.

There is a close interrelation between weather conditions and crop conditions, and between these and the amount of stem rust that develops. The tendency for stem rust to be more prevalent in growing seasons with high rainfall arises as a result of the interaction of a number of factors. A plentiful supply of moisture induces rapid succulent crop growth, resulting in tall, dense stands of grain. Deficient rainfall has the opposite effect. Air circulates less freely within a tall, dense stand of grain than within a thin, short one, so that following a rain or heavy dew the plants and the air surrounding them dry much less rapidly in the former than in the latter type of crop. Conditions favourable for infection are, therefore, present for a longer space of time, and the more frequently rain occurs the more often are such conditions present. Furthermore, stem rust develops more vigorously and produces larger pustules in succulent (7, p. 239) than in

drier firmer tissue, so that the pustules produce more spores, and, therefore, more inoculum is available for distribution in wet than in dry seasons. Vigorous crop growth is dependent on suitable temperature conditions. So also is rapid rust development. A tendency, therefore, would be expected in the heavy rust years for the temperature during the critical month for the disease in Western Canada to be somewhat higher, that is to say, somewhat closer to the optimum temperature, than in the other two classes of years. Given suitable conditions of moisture and temperature, the amount of infection is dependent on the amount of inoculum and the time of its arrival in relation to the maturity of the crop. The failure of stem rust, therefore, to attain equal severity in Alberta and western Saskatchewan with that in eastern Saskatchewan and Manitoba seems to be attributable to the lighter rainfall and lower temperature in the former areas during the growing season, and particularly to the lesser amount and later arrival of inoculum.

Some of these relationships can be inferred from a study of Table 27, which gives for each day from June 23 to July 15 the hours of south wind (SE., S., SW.), the number of stem-rust spores intercepted by one square inch surface of glass slide, the rainfall, and the daily maximum and minimum temperatures, at Winnipeg, for two light rust years (1928 and 1931), two medium rust years (1930 and 1937), and two heavy rust years (1935 and 1938). This table shows that there is a distinct tendency for high concentrations of spores to be present in the atmosphere during periods of south wind. As such winds usually carry considerable moisture, there is, as might be expected, a tendency also for rainfall to be rather frequently associated with them. For example, in 1935 a south wind blew all day on June 23 and 24 and during the greater part of June 25. A heavy spore shower occurred on June 24 and continued into June 25. Over one-half inch of rain fell on June 24, a trace fell on June 25, and a light shower on the following day. A similar relation is evident in the same year between June 28 and July 2, and in 1938 between June 27 and July 1, as well as for shorter periods in other years. Thus two of the most important factors conducive to heavy infection, inoculum and moisture, are frequently brought together in proper sequence. Absence or paucity of spores during periods of south wind is mainly attributable either to the lack of inoculum farther south, as was the case on June 30 and July 1 and 2, 1928, or to rain washing the air comparatively free of spores, as evidently happened on July 3 to 6, 1938.

Furthermore, there is a tendency for temperatures to rise with the occurrence of south winds. This happens as a result of the arrival of warm air from the south. An examination of Table 27 shows that this happens rather regularly when south winds prevail for two or three days, as they frequently do. Thus, night temperatures tend to approach more nearly the optimum for infection. Besides, the higher temperatures tend to stimulate the rapid development of those infections that have already taken place. On the other hand, even though weather conditions are

favourable for stem-rust development, the disease can make little headway unless inoculum is abundant. This fact is emphasized by the comparative lightness of the attack in 1928 and 1931. Although weather conditions were favourable for stem-rust development throughout the growing season in 1928 and in late June and early July in 1931, heavy infection did not develop, largely it would seem, through lack of inoculum.

The occurrence of south winds with their concomitant weather conditions—higher moisture content and temperature—may give rise to short periods of warm humid, “muggy,” weather, frequently referred to by farmers as “rust weather.” Such weather conditions are generally found associated with the south-eastern sector of an atmospheric low pressure area as it passes eastwardly across the continent. This is the sector into which the warm air from the south, the “tropical” air of the meteorologists, flows. If stem-rust inoculum is present in the regions over which the south winds blow, it is carried northward by them. When the tropical air meets the cooler, and hence heavier, “polar” air, it is forced to rise, as as up an inclined plane, and becoming cooled deposits its moisture as rain. Rain occurs also on its western flank, where the cooler polar air pushes under it and forces it aloft (Figure 13). There is a good chance, therefore, that the introduction of inoculum and the occurrence of rain will be associated with periods of warm humid, “muggy,” weather. The belief that this sort of weather is a precursor of stem-rust outbreaks is, therefore, in the main, fully justified, although the weather is not the direct cause of the outbreaks.

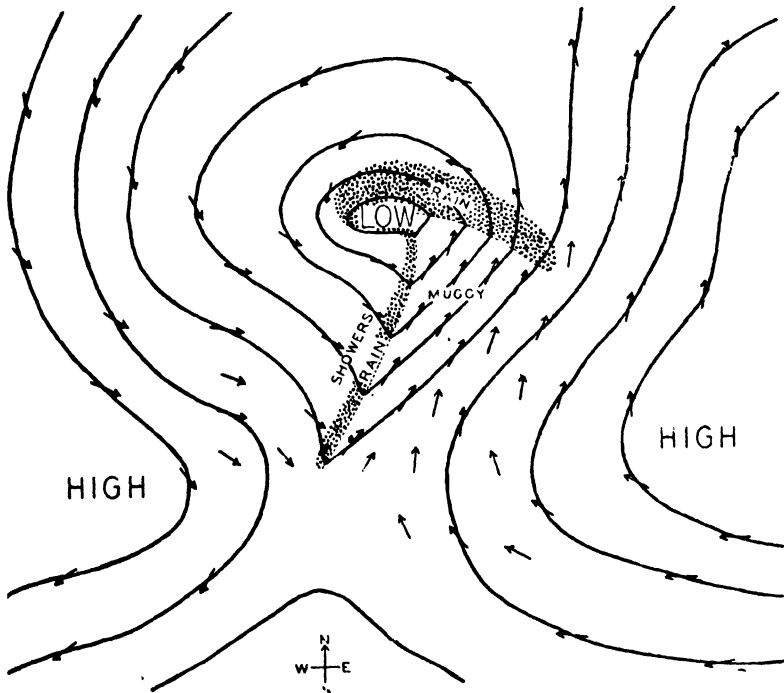


FIGURE 13. Diagrammatic representation of a low pressure area flanked by two high pressure areas. The wind direction in the different parts is indicated, as is also the humidity conditions often associated with the occurrence of south wind.

TABLE 27.—INTERRELATION OF SOME FACTORS INFLUENCING STEM-RUST OUTBREAKS IN WESTERN CANADA. HOURS OF SOUTH WIND, NUMBER OF UREDIO-SPORES INTERCEPTED, RAINFALL, AND AVERAGE TEMPERATURE (FAHRENHEIT), EACH DAY AT WINNIPEG, MANITOBA, FROM JUNE 23 TO JULY 15, FOR TWO LIGHT, TWO MEDIUM, AND TWO-HEAVY-RUST YEARS

Year	Factors	June										July													
		23	24	25	26	27	28	29	30	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
1928 (Light)	South wind																								
	Spores	0	0	0	2	15	15	2	24	24	15	1	5	19	1	0	0	4	4	5	0	11	24	18	
	Rainfall	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	43	—		
	Temperature	62	60	60	64	65	68	71	71	73	71	66	66	69	71	67	62	62	66	69	68	69	72	76	
1930 (Medium)	South wind																								
	Spores	2	12	10	0	3	11	13	1	19	24	23	8	0	8	22	4	14	0	10	0	0	24	18	
	Rainfall	—	2	—	—	—	—	—	—	5	4	5	2	—	—	8	—	5	—	3	5	17	161	480	
	Temperature	65	64	64	64	66	64	57	65	64	67	69	71	69	71	74	80	80	72	74	71	64	66	77	
1931 (Light)	South wind																								
	Spores	23	13	19	13	19	23	9	4	7	8	0	8	11	12	0	2	9	24	24	13	14	0	4	
	Rainfall	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	21	—	—	1	1		
	Temperature	64	69	73	71	78	86	83	82	77	68	60	60	65	63	59	60	64	69	71	68	71	70	73	
1935 (Heavy)	South wind																								
	Spores	24	24	20	5	0	23	24	23	24	17	5	18	0	2	19	17	15	10	3	0	1	9	14	
	Rainfall	9	240	52	—	—	10	17	37	7	22	7	12	5	—	1	—	3	—	3	12	7	6	50	
	Temperature	62	68	66	62	60	65	73	76	77	74	78	69	66	64	65	68	71	75	70	69	69	68	72	
1937 (Medium)	South wind																								
	Spores	22	6	12	6	11	0	8	16	21	0	11	6	24	10	4	19	6	0	0	0	0	3	0	
	Rainfall	4	9	—	2	—	1	—	—	—	—	—	1	10	180	2	1	—	82	—	—	1	12	1	
	Temperature	80	63	61	61	69	65	72	68	71	72	72	68	76	80	71	71	68	71	72	73	72	69	68	
1938 (Heavy)	South wind																								
	Spores	0	0	0	3	15	24	14	14	22	0	18	17	20	15	2	0	17	5	23	16	0	7	3	
	Rainfall	—	—	—	1	—	86	—	328	—	2	—	—	—	4	—	3	—	140	—	247	—	113	—	
	Temperature	71	66	62	56	67	66	67	72	70	71	75	75	73	72	72	63	63	68	71	78	63	67	71	

DISCUSSION

The main purpose of the investigation was to determine the source of stem-rust infection in Western Canada and to ascertain the cause of the variation from year to year in the intensity of the infection. The results of the investigation are summarized at the end of this paper. It is only necessary here to mention a few points that were not earlier given consideration.

There is abundant evidence to indicate that in Western Canada early infections arise largely or entirely from wind-borne urediospores, and that in some years and probably in all these spores originate at a considerable distance from this area—four or five hundred miles and in some years even farther. That they can be carried for long distances is not surprising. They are extremely small, and can readily be carried about by winds. Gassner (72) suggests that the minute echinulation of the surface of the spores increases their buoyancy, and thus they do not settle to earth so readily as if the surface were smooth. Ukkelburg (220) measured their rate of fall in still air, and found it to be 11.5 millimeters per second, approximately 136 feet per hour. He calculated that urediospores at a height of 5,000 feet and carried by a wind of 30 miles per hour would have a theoretical dispersal distance of between 1,100 and 1,200 miles. If the spores were at a higher level, or if the wind velocity were greater, the distance would be increased.

Urediospores of stem rust in large numbers reach a height of one mile (5,280 ft.) above the earth's surface and sometimes even nearly double that height. This was shown by Stakman and co-workers (203) in an investigation of the spore content of the upper air over the Mississippi Valley and by Peturson (162) in connection with the present investigation (Table 5) in Western Canada. Wherever stem rust is abundant, tremendous numbers of urediospores are produced, and, if not wet with dew or rain, they are readily blown away by winds, even by gentle breezes, but particularly by strong sudden gusts, which are of frequent occurrence on hot dry days. On such days, too, small whirlwinds are common, and strong upward convection currents are numerous. These currents rise at a much faster rate than the force of gravity causes the spores to fall, and hence the spores are carried aloft, probably to about as high levels as the rising air attains. Somewhere about the two-mile level, there is usually a marked thinning out in the number of fungal spores present in the air (136, 162, 198, 203, 233), but some types of spores have been found at a height of about four miles (166, 167).

Of course, it is a general rule that what goes up must come down, and rust spores are no exception. Always there is acting on them the force of gravity, but owing to their buoyancy their rate of fall in the lower air levels is very slow. According to Ukkelburg's (220) data, urediospores in still air would require more than a day and a half to settle to the ground from a height of one mile. While descending, as a result of the effect of gravity, they may, however, meet ascending air currents, and thus their sojourn in the atmosphere may be considerably prolonged. They may be brought down, however, from high levels relatively quickly by descending convection air currents. The descending cooler air, being of greater

density than the warm air at the earth's surface, displaces it, thus giving rise to the ascending currents. As the warm air rises, it gradually becomes cooler and, if it contains considerable water vapour, this vapour condenses. Condensation apparently can only occur if there are present particles of solid matter, such as of dust or smoke, to serve as "nuclei" on which the moisture can condense. Rust spores carried aloft can, no doubt, serve as such nuclei, and, as condensation of moisture on them proceeds, their buoyancy decreases and they tend to fall more rapidly than would dry spores. If the amount of condensation is pronounced, droplets of water may thus be formed and the spores may be brought down quickly in the resulting rain.

No attempt seems yet to have been made to investigate the dispersal pattern of spores liberated into the air at any particular place and height, and hence any discussion of the matter must be largely theoretical, although certain deductions can be drawn from observation of the infection pattern of stem rust in the field. Where a localized center of infection occurs, new infections, as a rule, are most numerous in the vicinity of the center, and become fewer in number as the distance from the center increases, the greatest distance of spread being in the direction that the prevailing wind blows (108, 113, 141, 158). Where an extensive area of heavy infection exists, the same general pattern of spread seems to obtain, but on a proportionately larger scale. From such an area, enormous numbers of spores are carried aloft, some to greater, some to lesser heights. As already indicated, the spore concentration is much greater at the lower than at the higher levels. If, therefore, the wind were blowing at the same rate at all levels, the spores in the lower levels would settle first, those at the higher levels later and at a greater distance from their place of origin. Owing, however, to the retarding effect of friction, and particularly to the obstruction offered by mountains, hills, forests, and large cities, the wind velocity is much reduced near the ground. The retarding effect decreases with increased height, so that at a height of 2,000 feet the velocity is considerably greater than at the surface of the earth. The tendency, therefore, is for the spores at the higher levels, in contrast with those at the lower levels, to be carried farther in proportion to their height, and, as they are less numerous, to be spread more thinly over the area where they finally settle. No doubt, many of the spores that settle early are picked up again by the wind and rising air currents and are carried farther onward, proceeding as it were by a succession of hops, and in diminishing numbers, but their rate of progress would be a good deal slower than that of those carried at the higher levels.

This theoretical pattern of spore spread seems to correspond, as would be expected, with the ascertained data, although such data are very limited. Lambert (113) reports that slides exposed at three feet from the ground for 20 hours at distances of 3, 6, and 69 feet from a heavily rusted planting of barberries, caught 160,000, 33,000, and 210 aeciospores, respectively, while a few days later slides exposed for a week at a distance of 3,300 feet intercepted 3,000 spores (approximately 355 per each 20 hours), and a slide 1 mile away collected a few spores after a 2-day exposure. Stakman (193) states that, in southern Minnesota, slides exposed for different periods of

time at 4 feet above ground level and at different distances from a heavily rusted barberry bush, intercepted aeciospores per square foot as follows:

In 2 days, at distance of 3 feet	7,000,000 spores
In 3 days, at distance of 90 feet	45,000 spores
In 1 week, at distance of $\frac{5}{8}$ mile	144,000 spores
In 1 week, at distance of 1 mile	100,000 spores

The number of aeciospores intercepted would be expected to vary considerably from day to day, depending on moisture conditions, and wind direction, and on the occurrence of upward air currents. As the distance from the source increased, the number of spores present in the air would undoubtedly tend to diminish.

Owing to the fact that the distribution of stations at which slides were exposed in Western Canada was more largely east and west instead of north and south, the slide-exposure data (Table 3) are of comparatively little value in checking the correctness of the theory in respect to wind-borne spores from the south, the direction in which the source of the early arriving inoculum lies. This deficiency is compensated to a slight extent by certain data for points in the Upper Mississippi Valley. Stakman (193) reports that during a strong south wind on June 10, 1929, 600 urediospores per square foot (between 5 and 6 spores per sq. in.) were caught near the level of grain plants in southern Minnesota, and that on June 16 the number was 800 per square foot. On July 4 and 5, about 3,800 per square foot (26 or 27 spores per sq. in.) were deposited at Fargo, N.D. At none of the stations in Manitoba or Saskatchewan at which slides were exposed in 1929 were any spores detected on June 10 or on July 4 and 5, excepting at Indian Head, Sask., where, on June 10, two spores were intercepted. On June 16 and 17, however, urediospores were present in Manitoba (but not in Saskatchewan) in relatively high concentrations (Table 3). It is evident, therefore, that the spore shower which occurred on June 16 in southern Minnesota continued northward into Manitoba on June 16 and 17, but that the ones on June 10 and July 4 and 5 did not.

Why spores should be present in Manitoba on June 16 and 17 and not on the other dates may be open to more than one explanation, but the most probable one is based on the circulation of the air on the dates in question. On June 16 and 17, a high atmospheric pressure system was present over the eastern and a low pressure one over the western part of the continent (Figure 10), so that a strong south wind blew up the Mississippi Valley for a great distance into Manitoba. On June 10, however, a low atmospheric pressure system was centered over northern Manitoba and Saskatchewan, with the result that a westerly wind was brought to southern Manitoba and a north-westerly one to southern Saskatchewan. Spores, therefore, present in the atmosphere over southern Minnesota would be carried in a north-eastern direction, towards north-western Ontario. A similar explanation holds for July 4 and 5. On the first of these dates, a low pressure area was situated to the north-east of Winnipeg, so that in Saskatchewan and Manitoba the wind blew from the north-west. On the second date the depression had moved farther eastward, as a result of which the weather in southern Saskatchewan and Manitoba was relatively calm, any wind present being chiefly from the west.

Two or three other instances may be given. Stakman (195) relates that strong south winds beginning on June 20, 1935, culminated in a heavy spore shower on June 24 in the State of Minnesota. Reference to Table 3 will show that on the latter date a high concentration of spores was present in the air over Winnipeg. The concentration was much less at Morden, and still less at Brandon, but such differences in spore number are common. In 1937, he (196) states that spore showers occurred in late May in the Upper Mississippi Valley and that there were fairly heavy ones in certain places about June 12. From June 18 to 24 inclusive, spore showers were rather heavy in much of this area, 5,000 spores per square foot (approximately 35 per square inch) being present on June 24 at Brookings, S.D., and on June 23 at Fargo, N.D., and during a 24-hour period (June 23-24) at St. Paul. It will be seen in Table 2 that some spores were present at Morden and Winnipeg on June 12 and also from June 18 to 24. A light, but distinct, spore shower occurred on June 23 at Winnipeg. The number of spores present in Manitoba between June 18 and 24 was considerably less than in the Upper Mississippi Valley, but this circumstance is probably due to the fact that, except on June 18 and on June 22 and 23, the high and low atmospheric pressure areas were not in a suitable position to bring a south wind from far down the Mississippi Valley, and consequently there was probably not a high concentration of spores present in the air, and hence the number that came as far north as Winnipeg was relatively small. At Winnipeg, on June 20, 21, and 24, there was, respectively, only 5, 2, and 6 hours of south wind. According to Stakman and Hamilton (202), heavy spore showers occurred in the Upper Mississippi Valley in 1938 on June 13 and 14. At Fargo, N.D., 1,248 spores per square foot (about 9 per sq. in.) were caught on June 13. From Table 2, it is seen that during the 2-day period June 13 and 14, the number of spores caught at Morden was 29, at Winnipeg 5, and at Brandon 8, per square inch.

There can be no doubt that the spore showers that occurred in Manitoba on these occasions were part and parcel of the showers that occurred in the Upper Mississippi Valley. They occurred during periods of south wind, and as indicated by Stakman, and Stakman and Hamilton, the spores constituting the showers, originated in infected areas lying to the south, apparently considerably far south, of the Upper Mississippi Valley. It is clearly evident, then, that under some circumstances spores originating in one area may be dispersed in considerable numbers a very long distance.

When once viable spores arrive in any district, it might be expected that whenever moisture and temperature conditions are favourable infection of susceptible crops would proceed uninterruptedly so long as such conditions persist. There seems to be the possibility, however, that the opportunities for infection to occur are more restricted than is usually supposed. For example, Weston (234, 235) found that in bright sunlight urediospores floating on water failed to germinate, but they germinated under conditions of low light intensities, and in direct sunlight when they were covered with green and blue filters. Apparently, then, even though moisture, either as dew or rain, is present on plants during the day, little or no infection would occur on those parts of the plants directly exposed to sunlight. Hart (81) and Hart and Forbes (82) found that closed stomata largely excluded the germ tubes of stem-rust spores, so that at night when

moisture conditions are likely to favour infection, the stomata remain closed and little infection can occur. In this connection, it may be mentioned that Allen (3, 4) found that in Kanred wheat only about 10% of the germ tubes succeed in entering the stomata, a fact which she attributed in part to the naturally small stomatal openings of this variety.

Closure of the stomata during the day may possibly also interfere occasionally with infection, but probably not to any very appreciable extent. The stomata of cereal plants are usually open in the morning, gradually close in the afternoon, and remain closed at night. Loftfield (122) found that there is a tendency for cereals to operate with many of their stomata closed, all being open only when the weather is cool, rather humid, and with sunlight of moderate intensity. Under unfavourable conditions, such as low atmospheric humidity or drought, the stomata may remain closed practically all day. This finding is in agreement with that of Maximov and Zernova (125), who showed that under drought conditions the stomata of wheat plants may remain closed the greater part of the day, opening only for an hour or two in the morning. If then, in a dry period, spores were present on the plants, and an opportunity for germination occurred during the day, infection might not be able to take place because of the closed stomata.

Epidemics of stem rust have been found usually to develop in growing seasons with comparatively high temperatures (113, 207, 215, 222, 224, 238), but it would seem that high temperatures must have less effect in some areas than in others on the ultimate amount of infection that may develop. Within limits, an increase in temperature accelerates the rate of stem-rust development. Stakman and Levine showed (208) that rust development is retarded 1 day for every 5 degrees the temperature falls below 66.5° F., and for every 10 degrees it rises above 70° F. At 66.5° F., fresh infections of stem rust require, say, about 1 week to produce spores, whereas at 61.5° F. they would accordingly require 1 day longer. During a period of 7 weeks, therefore, one more generation of spores could be produced at the former than at the latter temperature. On this basis, therefore, it would seem that before high temperatures could be effective in influencing the amount of rust present on the crop, infection would have to be present in an area for a period of approximately 7 to 8 weeks, that is to say, long enough to permit the production of an extra generation of spores. One additional generation, of course, may convert what would otherwise be a moderate infection into one of extreme severity.

Probably, therefore, the influence of warm temperatures on the amount of infection is most evident in areas where the inoculum must be built up from small beginnings, as it must be in areas where the source of infection is isolated spots of overwintered rust or infected barberry, and where the season is sufficiently long to permit the influence of temperature to find expression. For example, stem rust may start spreading from overwintered centres of infection in Texas during the latter part of April (113), and gradually spread northward up to the Mississippi Valley, finishing its course of destruction in that area with the ripening of crops in the northern part of Minnesota and North Dakota in early August, a period of approximately 15 weeks. With favourable moisture conditions, two more generations of spores could be produced during this period at the higher (66.5° F.)

than at the lower (61.5° F.) temperature. In the northern Mississippi Valley States, stem rust frequently begins to spread from infected barberries to cereals and grasses during late April and early May (189, 205). Between then and the time crops ripen in northern Minnesota and North Dakota, there is sufficient time, with a temperature of 66.5° F., for the rust to produce at least one generation of spores more than could be produced if the temperature during the period was 5 degrees lower.

Where the developmental period of stem rust on crops is less than 7 weeks, there would probably be insufficient time for an extra generation of spores to develop, even though temperatures were optimum. For example, in Western Canada, there is, on an average, a period of about 4 or 5 weeks in which stem rust has an opportunity to multiply on the bulk of the crop. This is largely due to the fact that the grain-growing area has its greatest extent east and west, so that much of the crop ripens about the same time. A delay of 2 or 3 weeks in the ripening of the crop, such as happened in 1927, would undoubtedly give opportunity for the production of one or two extra generations of spores, and a consequent steep increase in the amount of infection. In 1927, however, the extra spore generations were made possible by the slow maturing of the crop owing to cool damp weather, not through an acceleration in rust development due to high temperatures. The influence of high temperatures on the intensity of stem-rust infection in Western Canada appears to find expression largely in the increased amount of inoculum that may be induced by high temperature in the Mississippi Valley and thus made available for wind dispersal into Western Canada. If the somewhat higher temperatures in July, of the heavy rust years in the latter area, had any marked effect on the destructiveness of the rust in these years, the effect was probably brought about by a physiological disturbance in the plants themselves as a result of higher loss of water (from plants and soil), rather than by an appreciable increase in the amount of infection induced by high temperatures.

Finally, it may be observed that, according to the meteorological data presented in this paper, years in which stem rust was of moderate to severe intensity in Western Canada were not strikingly different in respect to weather conditions from at least some of the years in which stem rust was of comparatively little consequence. The mean temperature for the 3-month period, June to August, was practically the same for the three classes of years, and although the mean temperature for July in the heavy rust years (69.4° F.) was slightly greater than in the medium (67.9° F.) or the light (67.8° F.) rust years, July temperatures in practically all years were sufficiently high to promote vigorous rust development. Spring and summer rainfall, on an average, was higher in the heavy and medium rust years than in the light rust years, but to a considerable extent the excess in the former two classes of years is attributable to the exceptionally heavy precipitation in one or two years of each class. Likewise, there were, on an average, more days with rain during the three summer months of the heavy and medium rust years than of the light rust years. Whether or not dews were more frequent or copious in one class of year than in another, is not known. Broadly speaking, it would seem that those meteorological factors that are usually regarded as influencing stem-rust development, tended to be, on an average, slightly less favourable in the light rust years

than in the other two classes of years. Nevertheless, it would seem that the actual severity of the disease in most years was more closely related to the amount of wind-borne inoculum that arrived and the time of its arrival than to any special weather conditions that prevailed.

SUMMARY

1. A study has been made of the epidemiology of stem rust, particularly of wheat stem rust, in Western Canada.

2. The disease regularly appears first in southern Manitoba, more often than not in the Red River Valley, and later farther northward and westward, the time of its appearance in Manitoba being late June or early July and in Alberta a month or more later. The area most severely affected is Manitoba and eastern Saskatchewan.

3. Local sources of infection are virtually absent. Barberry, although never an important source of infection in Western Canada, had been eradicated by the time the present investigation was undertaken; and no actual case of overwintering has ever been established, although occasionally a low percentage of urediospores may survive the winter. All spore viability seems to be lost before new growth of grasses or cereals is available for infection in late spring and early summer.

4. Almost invariably inoculum is present in the air earlier over Manitoba, usually first over the Red River Valley, than over Saskatchewan, and over Saskatchewan earlier than over Alberta. In any given district, inoculum has always been found present in the air in advance of infections in the field.

5. Initial inoculum consists largely, if not entirely, of wind-borne spores that originate outside of Western Canada. From time to time subsequent influxes of spores arrive to augment the locally produced inoculum arising as a result of infections by the earlier wind-borne spores.

6. The similarity year by year in the amount of infection and in the physiologic races present in Western Canada and in the Northern Mississippi Valley indicates strongly that the bulk of the wind-borne inoculum originates in the latter area.

7. There is an evident association between years of high spring and summer rainfall and years of medium and heavy stem-rust infection, although the association is not necessarily a close one and seems to be dependent on the presence of some other factor or factors, the chief one apparently being the amount of inoculum. The excess rainfall of the medium and heavy rust years over the light rust years, is not concentrated in any one particular month but is spread over the 5-month period April to August, the April to May and July rainfall, however, being more consistently above average than the June and August rainfall.

8. Similarly, years with an above-average frequency of days with rain during the spring and summer months tend to be associated with years of medium and heavy stem-rust infection. The association does not seem to be close and seems to be dependent on the amount of inoculum that is present.

9. Misty and foggy weather is of comparatively rare occurrence in Western Canada and is, therefore, of little consequence in the promotion of stem-rust epidemics in this area.

10. A tendency seems to be evident for the relative humidity to be slightly higher in years of medium or severe outbreaks than in years when infection was less pronounced, but, probably not high enough to have any appreciable influence on the amount of infection.

11. The frequent occurrence of nights with copious dew in Western Canada is undoubtedly of importance in promoting spore germination and plant infection in this region.

12. For the growing season, the mean temperature in Western Canada tended to be slightly higher in light rust years than in heavy rust years, but slightly lower than in medium rust years. On the other hand, the mean temperature for the month of July in the bad rust area was slightly higher in the heavy rust years than in the light rust years, but probably not sufficiently higher to affect appreciably the amount of stem rust.

13. The mean minimum temperature for the period June 20 to August 4—the period in which stem rust makes most rapid development and spread in Western Canada—tended to be somewhat higher in the heavy rust years and to some extent in the medium rust years than in the light rust years. The chief effect of the lower minimum temperature in the light rust years is probably to retard rust development rather than to decrease the number of infections.

14. No relationship appears to exist in Western Canada between the number of hours of bright sunlight during the growing season and the occurrence of stem-rust epidemics, there being apparently sufficient sunlight in any season to promote vigorous rust development.

15. A close association is evident in Manitoba between the occurrence of periods of south wind and the occurrence of high stem-rust (and leaf-rust) spore concentrations in the air during the period June 12 to July 20. The association is somewhat less evident in Saskatchewan and seems largely to disappear in Alberta.

16. Although the number of hours, as well as of days, with south wind during this period were slightly greater in the heavy rust years than in the light rust years, the excess has probably no particular significance in respect to the number of spores introduced.

17. Broadly speaking, it does not appear that winds favouring the introduction of spores into different parts of Western Canada were more frequent or of greater duration in heavy rust years than in light rust years.

18. Among the factors contributory to the occurrence of more frequent and severe outbreaks of stem rust in Manitoba and eastern Saskatchewan than in western Saskatchewan and Alberta, may be mentioned, in respect to the former areas, their closer proximity to the source region of inoculum, greater number of hours of wind favouring inoculum introduction, and their somewhat higher rainfall and temperature. The first two of these factors tend to ensure a greater abundance of inoculum to those areas.

19. Field infection of wheat in Manitoba, and, as far as known, in the other two provinces of Western Canada, occurs in an occasional year at the time wheat is heading, but in most years after this crop has come into head. Nevertheless, the time at which field infections appear seems to be determined, not by the stage of crop maturity, but by the time of inoculum arrival and the subsequent weather conditions.

20. To a marked extent the establishment of epidemic conditions in Western Canada seems to be dependent on the early arrival of an abundant supply of wind-borne inoculum. In the medium rust years, wind-borne inoculum became plentiful considerably later than in the heavy rust years; and in the light rust years, with one exception, it was not abundant at all or only became abundant late in the season.

21. With respect to the length of time required for the wheat crop to mature, there was little or no difference between the heavy rust years and the light rust years. In the heavy rust years, however, seeding was usually a few days later than average, and, as infection appeared about the usual time and increased rapidly, the crop was subjected during most of its fruiting period to severe attack. In the medium rust years, moderate to severe infection only became established after the fruiting period of the bulk of the crop was about half or more completed.

22. The interrelation of various factors influencing the development of stem rust in Western Canada is discussed, and an explanation is given in justification of the widely-held belief that a period of moist warm—"muggy"—weather is frequently a precursor of a heavy stem-rust attack.

ACKNOWLEDGMENTS

Some phases of this investigation were undertaken in 1918 by Dr. W. P. Fraser and his associates at the Dominion Laboratory of Plant Pathology, Saskatoon, Saskatchewan, in co-operation with the branch laboratory at Indian Head, Sask., and the Winnipeg Laboratory (beginning 1923), and were continued until 1925, when the investigation was transferred to the latter Laboratory. The early phases of the investigation included rust surveys, barberry surveys and eradication, overwintering studies, and some slide exposures at Winnipeg in 1918 by Dr. Margaret Newton and subsequently at Saskatoon by Dr. P. M. Simmonds. Summary accounts of these earlier studies are contained in the Reports of the Dominion Botanist, Department of Agriculture, Ottawa, Canada, for the respective years. From 1923 to 1925, the Winnipeg Laboratory, in charge of Dr. D. L. Bailey, carried on rust surveys, and continued the barberry survey in Manitoba, and in 1925 initiated the aeroplane-slide exposures and recommenced the stationary-slide exposures at Winnipeg. During the years 1917 and 1925, several members of the Staff of the Manitoba Agricultural College, particularly Prof. V. W. Jackson, took an active part in the campaign against barberry, and the early elimination of this shrub from the public parks of Winnipeg was largely due to the efforts of Prof. A. H. R. Buller, of the University of Manitoba.

In the reorganization of the investigation in the autumn of 1925, some phases were much expanded, particularly the rust surveys and the slide-exposure studies. The Saskatoon Laboratory, in charge of Dr. Simmonds—

Dr. Fraser having in that year been appointed Professor of Biology in the University of Saskatchewan—assumed responsibility for rust surveys and overwintering studies in Saskatchewan and Alberta, and for the stationary slide exposures in those two provinces. In 1928, when the Dominion Laboratory of Plant Pathology was organized at Edmonton, Alta., under Dr. G. B. Sanford, that Laboratory undertook responsibility for the rust surveys in Alberta. The rust surveys made by the three Laboratories have been supplemented by the hearty co-operation of the Departments of Plant Pathology and of Agronomy of the Universities of the three Prairie Provinces. The Superintendents and Staffs of the several Dominion Experimental Farms in these provinces have also given valuable assistance, particularly in connection with the exposure of slides. Slide exposures on aeroplane flights were made possible by the kind assistance of the Committee on Civil Government Air Operation afforded through the excellent co-operation of the Branch of the Royal Canadian Air Force stationed at Winnipeg. Dr. J. Patterson, Controller, Meteorological Division, Air Services of Canada, kindly provided weather data that were unpublished or not readily accessible, and several of the Observers of this Division, in the three provinces, gladly assisted in the exposure of slides and in providing current weather observations. Mr. D. C. Archibald, of the same Division, has given helpful advice concerning certain meteorological aspects of the study. Much of the actual work involved in the surveys and slide examinations was performed by different members of the Staffs of the three plant pathological laboratories, particularly by Dr. B. J. Sallans of the Saskatoon Laboratory and Mr. Bjorn Peturson of the Winnipeg Laboratory, both of whom have contributed largely to the investigation. Mr. A. M. Brown kindly prepared the photographs. Grateful acknowledgment is made to these and all others who have assisted in the investigation; and to the Dominion Botanist, Dr. H. T. Güssow, under whose general supervision the work was carried on, for his constant interest and generous support.

REFERENCES

1. ABBOTT, E. V. Further notes on plant diseases in Peru. *Phytopath.* 21 : 1061-1071. 1931.
2. ABERHOLD, R. and W. RUHLAND. Die Frage der Überwinterung und Verbreitung der Getreideroste. *Mitt. Kais. Biolog. Anst. f. Land.-u. Forstwirtsch.* Heft 2. 3-5. 1906.
3. ALLEN, RUTH R. A cytological study of infection of Baart and Kanred wheats by *Puccinia graminis tritici*. *Jour. Agr. Res.* 23 : 131-151. 1923.
4. ALLEN, RUTH R. Cytological studies of infection of Baart, Kanred, and Mindum wheats by *Puccinia graminis tritici* Forms III and XIX. *Jour. Agr. Res.* 26 : 571-604. 1923.
5. APPEL, O. and A. SCHEIBE. Beobachtungen über die Verbreitung der einzelnen Getreiderosten in Deutschland, insbesondere im Jahre 1930. *Mitt. Deutsch. Landw. Gesellsch.* 46 : 61. 1931.
6. ARRHENIUS, O. Berberisbuskens förekomst i s. Stockholms län. *Landtmannen* 13 : 83. 1930.
7. ARTHUR, J. C. The plant rusts. Pp. 1-446. John Wiley & Sons, Inc., New York; Chapman & Hall, Ltd., London. 1929.
8. ASPERGER, K. Zur Frage der Überwinterung von *Puccinia triticea* Erikss. und *Puccinia graminis* Pers. in ihren Uredoformen. *Zeitschr. Pflanzenkrankh.* 45 : 131-143. 1935.

9. ATKINS, I. M. Ecological factors in north Texas related to the 1935 stem rust epidemic. U.S. Dept. Agr., Plant Dis. Repr., Sup. 93 : 31-41. 1936. (Mimeographed.)
10. BAILEY, D. L. The epidemiology of cereal rusts in Manitoba. *In* Report of the Dominion Botanist for 1924. Canada Dept. Agr. Ottawa, 42-43. 1925.
11. BANKS, JOSEPH. An account of the mildew. *Ann. Agr.* 43 : 514-527. 1805.
12. BAUDYS, E. Phytopathological notes VI. *Abst. in Rev. Appl. Mycol.* 10 : 295-296. 1931.
13. BEAUVERIE, J. On the development of wheat rusts in relation to climatic conditions. *Rept. Intern. Conf. Phytopath. & Econ. Ent., Holland, 1923.* 201-203. 1923.
14. BEAUVERIE, J. Sur les rapports existant entre le developpement des rouilles du blé et le climat. *Compt. Rend. Acad. d. Sci.* 176 : 529-531. 1923.
15. BEAUVERIE, J. Sur la germination des urédiospores des rouilles du blé. *Compt. Compt. Rend. Acad. d. Sci.* 179 : 993-996. 1924.
16. BEDFORD, S. E. Report of Experimental Farm for Manitoba. *In* Canada Dept. Agr. Exp. Farms Rept., Ottawa, 1896. 321-376. 1897.
17. BEDFORD, S. E. Report of Experimental Farm for Manitoba. *In* Canada Dept. Agr. Exp. Farms Rept., Ottawa. 1902. 279-318. 1903.
18. BENSAUDE, MATHILDE. Notes on wheat diseases in Portugal. *Abst. in Rev. Appl. Mycol.* 8 : 637-638. 1929.
19. BENSAUDE, MATHILDE. Black rust of cereals. *Abst. in Rev. Appl. Mycol.* 9 : 704-705. 1930.
20. BENSAUDE, MATHILDE. (Discussion on dissemination of cereal rusts). *Proc. 5th Intern. Bot. Cong. Cambridge, 1930.* 416. 1931.
21. BOLLEY, H. L. A preliminary report upon the relation of time of seeding and period of development to the development of rusts and smuts of oats. *Proc. 17th Ann. Meet. Soc. Promotion Agr. Sci.* 1896. 70-75. 1896.
22. BOLLEY, H. L. Einige Bemerkungen über die symbiotische Mykoplasmatheorie bei dem Getreiderost. *Centralbl. f. Bakt. II.* 4 : 887-896. 1898.
23. BOLLEY, H. L. Cause of wheat rust, its method of attack, conditions favourable to infection and rust development, and what to do. *North Dakota Agr. Exp. Sta. Press Bull.* 20. 1904.
24. BOLLEY, H. L. and F. J. PRITCHARD. Rust problems. Facts, observations and theories. Possible means of control. *North Dakota Agr. Exp. Sta. Bull.* 68. 1906.
25. BRACKEN, J. Lessons from the rust epidemic of 1916. *Saskatchewan Dept. Agr. Bull.* 50. 1917.
26. BREGA, C. Further observations on the effect of the date of sowing upon the development of cereal rust. *Abst. in Rev. Appl. Mycol.* 8 : 93. 1929.
27. BROADBENT, W. H. Report of the barberry and the black rust of wheat survey in southwest Wales. *Great Britain Jour. Min. Agr.* 28 : 117-123. 1921.
28. BRUSCHETTI, C. On the germinative capacity of the uredospores of wheat rusts. *Abst. in Rev. Appl. Mycol.* 12 : 498. 1933.
29. BULLER, A. H. R. Essays on wheat. Pp. 1-339. MacMillan Co., New York. 1919.
30. BURTON, G. J. L. (Discussion on dissemination of cereal rusts). *Proc. 5th Intern. Bot. Cong. Cambridge, 1930.* 415. 1931.
31. BUTLER, E. J. The Indian wheat rust problem. *India Dept. Agr. Bull.* 1. 1903.
32. BUTLER, E. J. and J. M. HAYMAN. Indian wheat rusts. *Mem. Dept. Agr. India, Bot. Ser.* 1 : 1-52. 1906.
33. CARLETON, M. A. Cereal rusts in the United States. *U.S. Dept. Agr. Bull.* 16. 1899.
34. CARLETON, M. A. Lessons from the grain rust epidemic of 1904. *U.S. Dept. Agr. Farmers' Bull.* 219. 1905.
35. CASSELL, R. C. Effect of temperature on urediospore germination and germ tube development of five physiologic races of *Puccinia graminis tritici*. *Phytopath.* 29 : 4. 1939.

36. CASSELL, R. C. Effect of temperature on infection and development of eight physiologic races of *Puccinia graminis tritici* on wheat seedlings. *Phytopath.* 29 : 4. 1939.
37. CHABROLIN, C. La rouille noire du blé en Tunisie. *Rev. Path. vég. et Ent. agr.* 16 : 49-58. 1929.
38. CHATTERJEE, G. A note on an apparatus for catching spores from the upper air. *Indian Jour. Agr. Sci.* 1 : 306-308. 1931.
39. CHRISTMAN, A. H. Observations on the wintering of grain rusts. *Trans. Wisconsin Acad. Sci. Arts & Letters.* 15 : 98-107. 1904. (Pub'd. 1905).
40. COBB, N. A. Contributions to an economic knowledge of Australian rusts (Uredineae). *Agr. Gaz. New South Wales* 3 : 181-212. 1892.
41. CONNERS, I. L. Barberry (or *Berberis*). In *Ann. Rept. Can. Plant Dis. Survey for years 1933 to 1940.* Canada Dept. Agr., Ottawa, p. 65, 1933; 80, 1934; 65, 1935; 72, 1936; 72, 1937; 98, 1938; 101, 1939; 89, 1940.
42. CORNELLI, E. Notes on the development of rusts of wheat. *Rev. Appl. Mycol.* 12 : 497. 1933.
43. COTTON, A. D. Report on the occurrence of fungus, bacterial and allied diseases on crops in England and Wales for the years 1920-1921. Ministry of Agriculture and Fisheries (London), Misc. Pub. 38. 1922.
44. CRAIGIE, J. H. Economic diseases of field crops in Manitoba. Economic Survey Board, Province of Manitoba. 1939.
45. CRAIGIE, J. H. Aerial dissemination of plant pathogens. *Proc. Sixth Pacific Sci. Cong. Berkeley and Palo Alto, Calif.* 1939. 4 : 753-767. 1940.
46. CREPIN, C. Observations sur les rouilles des cereales en 1924 à Grignon. *Rev. Path. vég. et Ent. agr.* 11 : 317-320. 1924.
47. CREPIN, C. Note sur la rouille noire. *Compt. Rend. Acad. Agr. France*, 17 : 734-739. 1931.
48. CUNNINGHAM, G. H. The rust fungi of New Zealand. Pp. 1-261. John McIndoe, Dunedin, N.Z. 1931.
49. DARWIN, CHARLES. Journal of researches into the natural history and geology of the countries visited during the voyage of H.M.S. *Beagle* round the world. 4th ed., pp. 1-381. Ward Lock & Co., London, New York, and Melbourne. 1889.
50. DAWSON, W. J. Some problems of economic biology in East Africa (Kenya Colony). *Ann. Appl. Biol.* 8 : 83-100. 1921.
51. DE BARY, A. Neue Untersuchungen über die Uredineen, insbesondere die Entwicklung der *Puccinia graminis* und der Zusammenhang derselben mit *Aecidium berberis*. *Monatsber. der Akad. der Wissen. Berlin. Sitz.* 12 : 15-50. 1865.
52. DODOFF, D. N. Die epidemische Entwicklung der Weizenroste in Nordbulgarien im Jahre 1932. *Phytopath. Zeitschr.* 6 : 111-112. 1933.
53. D'OLIVEIRA, B. Aspectos actuais do problema das ferrugens. *Palestras agron.* 2 : 5-77. 1940.
54. DUCOMET, V. Pathologie végétale. Pp. 1-298. (Librairie des Sciences agricoles. Charles Amat, Editeur, 11 rue de Mazieres). Paris. 1908.
55. DUCOMET, V. Les rouilles des cereales en automne et en hiver. *Rev. Path. vég. et Ent. agr.* 12 : 21-27. 1925.
56. DUCOMET, V. Les rouilles du blé au cours de la campagne 1925-1926. *Rev. Path. vég. et Ent. agr.* 14 : 39-44. 1927.
57. DURRELL, W. L. and E. A. LUNGREN. Barberry eradication and sources of black stem rust in Colorado. *Colorado Agr. Exp. Sta. Bull.* 315. 1927.
58. DURRELL, W. E. and J. H. PARKER. Comparative resistance of varieties of oats to crown and stem rusts. *Iowa Agr. Exp. Sta. Res. Bull.* 62. 1920.
59. ERIKSSON, J. and E. HENNING. Die Getreideroste, ihre Geschichte, Natur, sowie Massregeln gegen dieselben., pp. 1-463. P. A. Norstadt & Söner, Stockholm. 1896.
60. FERDINANDSEN, C. The campaign against *Berberis* in Denmark and its results. *Abst. in Rev. Appl. Mycol.* 4 : 268. 1925.

61. FOËX, ET. Rouilles des céréales., pp. 1-116. Coulet et Fils, Montpellier. 1908.
62. FOËX, ET., MLLE. Gaudineau, and M. Guyot. Les rouilles des cereales en 1923 et 1924 dans région parisienne. Rev. Path. vég. et Ent. agr. 11 : 198-211. 1924.
63. FORWARD, D. F. The influence of altered host metabolism upon modification of the infection type with *Puccinia graminis tritici* form 21. Phytopath. 22 : 493-555. 1932.
64. FRASER, W. P. The cereal rusts. Ann. Rept. Quebec Soc. Protect. Plants, 1914-15. 116-120. 1915.
65. FRASER, W. P. The outbreak of wheat rust in 1916. Month. Bull. Agr. Statist. Dept. Trade and Commerce, Ottawa, Canada. 11 : 61-67. 1918.
66. FRASER, W. P. Wintering over of the urediniospores of stem rust. In Reports of the Dominion Botanist for the years 1921, 1922, 1923. Canada Dept. Agr., Ottawa, 1921, 1922, 1923.
67. FREEMAN, E. M. and E. C. JOHNSON. The rusts of grain in the United States. U.S. Dept. Agr. Bull. 216. 1911.
68. FRIEDRICHSON, G. A. Wheat rust in the irrigated districts of the Trans-Volga Region. Abst. in Rev. Appl. Mycol. 16 : 661-662. 1937.
69. GARBOWSKI, L. and H. JURASZKOWNA. Essais d'identification des formes biologiques de la rouille *Puccinia graminis tritici*, provenant du territoire de Pologne. (Note preliminaire). Rev. Path. vég. et Ent. agr. 21 : 45-55. 1934.
70. GASSNER, G. Die Getreideroste und ihr. Auftreten im subtropischen östlichen Sudamerika. Centralbl. f. Bakt. II. 44 : 305-381. 1915.
71. GASSNER, G. Untersuchungen über die Abhängigkeit des Auftretens der Getriede-oste vom Entwicklungszustand der Nahrpflanze und von äusseren Faktoren. Centralbl. f. Bakt. II. 44 : 512-617. 1915.
72. GASSNER, G. Beiträge zur Frage der Überwinterung und Verbreitung der Getreide-oste im subtropischen Klima. Zeitschr. f. Pflanzenkrank. 26 : 329-374. 1916.
73. GASSNER, G. Neue Festellungen über Auftreten und Verbreitung der Getreiderost-arten in Südamerika. Phytopath. Zeitschr. 4 : 189-203. 1931.
74. GASSNER, G. Über Verschiebung der Rostresistenz während der Entwicklung der Getreidepflanzen. Phytopath. Zeitschr. 4 : 549-596. 1932.
75. GASSNER, G. and E. PIESCHEL. Untersuchungen zur Frage der Uredoüberwinterung der Getreideroste in Deutschland. Phytopath. Zeitschr. 7 : 355-392. 1934.
76. GASSNER, G. and W. STRAIB. Untersuchungen über die Infektionsbedingungen von *Puccinia glumarum* und *Puccinia graminis*. Arb. Biol. Reichsanst. 16 : 609-629. 1928.
77. GONZALA, F. R. Cereal rusts. Abst. in Rev. Appl. Mycol. 5 : 658. 1926.
78. GOULDEN, C. H., M. NEWTON, and A. M. BROWN. The reaction of wheat varieties at two stages of maturity to sixteen physiologic forms of *Puccinia graminis tritici*. Sci. Agr. 11 : 9-25. 1930.
79. GREANEY, F. J. Cereal rust losses in Western Canada. Sci. Agr. 16 : 608-613. 1936.
80. HANSEN, H. R. Severity of attacks of black stem rust in Denmark 1887-1921. Phytopath. 13 : 404-407. 1923.
81. HART, Helen. Relation of stomatal behaviour to stem-rust resistance in wheat. Jour. Agr. Res. 39 : 929-948. 1929.
82. HART, HELEN and I. L. FORBES. The effect of light on the initiation of rust infection. Phytopath. 25 : 715-725. 1935.
83. HART, HELEN and KAROL ZALESKI. The effect of light intensity and temperature on infection of Hope wheat by *Puccinia graminis tritici*. Phytopath. 25 : 1041-1066. 1935.
84. HARTER, L. L. Podblight of the lima bean caused by *Diaporthe phaseolorum*. Jour. Agr. Res. 11 : 473-504. 1917.
85. HEALD, F. D. Manual of Plant Diseases. Pp. 1-891. McGraw-Hill Book Co., Inc., New York. 1926.

86. HEMMI, T. On the distribution of cereal rusts in Japan and the relation of humidity to germination of urediniospores of some species of *Puccinia*. Proc. 5th Pacific Sci. Cong., Canada, 1933. 4 : 3187-3194. 1934.
87. HENNING, E. Lagstiftningen mot Berberis busken med särskild hänsyn till frågans nuvarande läge i vårt land. Tidskr. f. Landtman 37 : 1-15. 1916.
88. HENNING, E. Den norske berberislagen och dess forhistoria. Landtmannen; tidskrift for Sveriges jordbruk och dess binaringer. 27 (42) : 377-379. October 21, 1916.
89. HENNING, E. Predisponerande betingelser för svartrosthärjningar. Landtmannen; tidskrift för landtman. 9 (51) : 1023-1025 and 9 (52) : 1041-1043. December 18 and 25, 1926.
90. HILTNER, L. Der Schwartzrost des Getreides und die Berberitze. Flugblätter zur Förderung des Pflanzenbaues und des Pflanzenschutzes No. 36. May, 1920.
91. HITCHCOCK, A. S. and M. A. CARLETON. Second report on rusts of grain. Kansas Agr. Coll. Exp. Sta. Bull. 46. 1894.
92. HUMPHREY, H. B. Notes on incidence of cereal rusts, crop season 1937. U.S. Dept. Agr., Plant Disease Reporter 21 : 305-306. 1937. (Mimeographed).
93. HUMPHREY, H. B. Relation of upper-air mass movement to incidence of stem rust. Phytopath. 28 : 10. 1938.
94. HUMPHREY, H. B., E. C. STAKMAN, E. B. MAINS, C. O. JOHNSTON, H. C. MURPHY and W. M. BEVER. The rusts of cereal crops. U.S. Dept. Agr. Circ. 341. 1935
95. HURST, R. R. Cereal rust investigations. In Report of the Dominion Botanist for 1926. Canada Dept. Agr., Ottawa. 1927.
96. HUTCHESON, T. B. and K. E. QUANTZ. The effect of greenhouse temperatures on the growth of small grains. Jour. Amer. Soc. Agron. 9 : 17-21. 1917.
97. HWANG, L. The effect of light and temperature on the viability of urediospores of certain cereal rusts. Phytopath. 32 : 699-711. 1942.
98. JACKSON, V. W. Rusts and smuts of grain crops. Manitoba Dept. Agr. and Immigration. Extension Bull. 44. 1919.
99. JACKSON, V. W., W. P. FRASER, and D. L. BAILEY. The present status of the barberry eradication in Western Canada. Sci. Agr. 5 : 375-378. 1925.
100. JACZEWSKI, A. Studien über das Verhalten des Schwartzrostes des Getreides in Russland. Zeitschr. f. Pflanzenkrank. 20 : 321-359. 1910.
101. JENKIN, T. J. and KATHLEEN SAMPSON. Rust resistant trials with wheat. Welsh Plant-Breeding Sta. Bull. Ser. C. 1 : 41-49. 1921.
102. JOHNSON, A. G. AND J. G. DICKSON. Stem rust of grains and the barberry in Wisconsin. Wis. Agr. Exp. Sta. Bull. 304. 1919.
103. JOHNSON, E. C. Cardinal temperatures for the germination of uredospores of cereal rusts. Phytopath. 2 : 47. 1912.
104. JOHNSON, T. and M. NEWTON. The effect of high temperatures on the uredial development in cereal rusts. Can. Jour. Res. C, 15 : 425-432. 1937.
105. JOHNSON, T. and M. NEWTON. The influence of light and certain other environmental factors on the mature-plant resistance of Hope wheat to stem rust. Can. Jour. Res. C, 18 : 357-371. 1940.
106. JOHNSTON, C. O., L. E. MELCHERS, H. H. LAUDE, and J. H. PARKER. The stem rust epidemic of 1935 in Kansas. U.S. Dept. Agr., Plant Dis. Repr., Suppl. 92 : 19-30. 1936. (Mimeographed).
107. JOHNSTON, C. O., L. E. MELCHERS, and J. O. MILLAR. The stem-rust epidemic of 1937 in Kansas. U.S. Dept. Agr., Plant Dis. Repr. Suppl. 107. 83-94. 1938.
108. KEMPTON, F. E. Progress of barberry eradication. U.S. Dept. Agr. Circ. 188, 1921.
109. KIKOINA, R. Wheat rust in the Azoff-Black Sea and North Caucasus regions, and their control. Abst. in Rev. App. Mycol. 15 : 785. 1936.
110. KLEBAHN, H. Beiträge zur Kenntnis der Getreideroste. II. Zeitsch. f. Pflanzenkrank, 10 : 70-96. 1900.
111. KLEBAHN, H. Die wirtswechselnden Rostpilze. Pp. 1-447. Gebrüder Borntraeger, Berlin. 1904.
112. LAGERHEIM, G. Ueber das Vorkommen von europäischen Uredineen auf der Hochebene von Quito. Botanisches Centralblatt 54 : 324-377. 1893.

113. LAMBERT, E. B. The relation of weather to the development of stem rust in the Mississippi Valley. *Phytopath.* 19 : 1-71. 1929.
114. LATHBURY, R. J. Report of Acting Senior Plant Breeder. Kenya Dept. Agr. Rept. 1933. 182-200. 1934.
115. LAURITZEN, J. I. The relation of temperature and humidity to infection by certain fungi. *Phytopath.* 9 : 7-35. 1919.
116. LEHMANN, E., A. BADER, G. MITTMAN, and O. SCHNITZLER. Berberitzenverbreitung und Schwarzrostauftreten in Württemberg. *Landw. Jahrb.* 80 : 1. 1-37. 1934.
117. LEHMANN, E., H. KUMMER, and H. DANNEMANN. Der Schwarzrost seine Biologie und seine Bekämpfung in Verbindung mit der Berberitzenfrage. pp. 1-584. J. F. Lehmann, München and Berlin. 1937.
118. LEVINE, M. N. Biometrical studies on the variation of physiologic forms of *Puccinia graminis tritici* and the effects of ecological factors on the susceptibility of wheat varieties. *Phytopath.* 18 : 7-124. 1928.
119. LIND, J. Effect of destruction of the barberry (*Berberis vulgaris*) on the common rust of wheat (*Puccinia graminis*) in Denmark. *Intern. Rev. Sci. Prac. Agr.* 7 : 442. 1915.
120. LIND, J. Berberisbusken og Berberisloven. *Tidsskr. for Planteavl.* 22 : 729-780. 1915.
121. LINDFORS, T. Berberisutrotningen i Sverige. *Landtmann* 9 : 412-413. 1926.
122. LOFTFIELD, J. V. G. The behaviour of stomata. *Carnegie Inst. Wash. Pub.* 314. Washington, D.C. 1921.
123. MARTIN, F. J. and R. E. MASSEY. Experiments on wheat growing in the Sudan. Wellcome Tropical Research Laboratories, Chemical Section, Publication No. 19, Khartoum, 1921.
124. MATTRAS, H. Observations sur les rouilles du blé faites à Versailles en 1931 et 1932. *Ann. des Epiphytes* 18 : 384-397. 1932.
125. MAXIMOV, N. A. and L. K. Zernova. Behaviour of stomata of irrigated wheat plants. *Plant Physiology* 11 : 651-654. 1936.
126. MAXWELL, IRIS and G. B. WALLACE. Black rust in Scotland. *Trans. Brit. Mycol. Soc.* 11 : 138-145. 1926.
127. McALPINE, D. The life-history of the rust of wheat. *Victoria Dept. Agr. Bull.* 14, 1891.
128. McALPINE, D. The rusts of Australia. Pp. 1-349. Melbourne, Australia. 1906.
129. McKILLICAN, W. C. Experiments with wheat at the Dominion Experimental Farm, Brandon, Manitoba. A survey 1889-1923. *Canada Dept. Agr. Bull.* 42. N.S. 1924.
130. MEHTA, K. C. Observations and experiments on cereal rusts in the neighbourhood of Cambridge, with special reference to their annual recurrence. *Trans. Brit. Mycol. Soc.* 8 : 142-176. 1923.
131. MEHTA, K. C. Annual recurrence of rusts on wheat in India. *Proc. Indian Sci. Cong.* 16 : 199-223. 1929.
132. MEHTA, K. C. Annual outbreaks of rust on wheat and barley in the Plains of India. *Indian Jour. Agr. Sci.* 1 : 297-301. 1931; *Proc. 5th Intern. Bot. Cong., Cambridge*, 1930. 413-414. 1931.
133. MEHTA, K. C. (Discussion on dissemination of cereal rusts.) *Proc. 5th Intern. Bot. Cong., Cambridge*, 1930. 415, 1931.
134. MEHTA, K. C. Rusts of wheat and barley in India. A study of their annual recurrence, life-histories, and physiologic forms. *Indian Jour. Agr. Sci.* 3 : 939-962. 1933.
135. MEHTA, K. C. Further studies on cereal rusts in India. *Sci. Monogr. Coun. Agr. Res. India*, 14. Pp. 1-224. Government of India Press, Calcutta. 1940.
136. MEIER, F. C., J. A. STEVENSON, and V. K. CHARLES. Spores in the upper air. *Phytopath.* 23 : 23. 1933.
137. MELANDER, L. W. Effect of temperature and light on development of the uredial stage of *Puccinia graminis*. *Phytopath.* 21 : 109. 1931; *Jour. Agr. Res.* 50 : 861-880. 1935.

138. MELCHERS, L. E. Plant disease problems in Egypt. Trans. Kansas Acad. Sci. 35 : 39-61. 1932.
139. MELCHERS, L. E. The wheat stem rust epidemic of Kansas in 1940. U.S. Dept. Agr., Plant Dis. Repr. Suppl. 132 : 95-103. 1941. (Mimeographed).
140. MELCHERS, L. E. and C. O. JOHNSTON. The wheat stem and leaf rust epidemics of 1938 in Kansas. U.S. Dept. Agr., Plant Dis. Repr. Suppl. 116 : 51-68. 1939. (Mimeographed).
141. MELHUS, I. E., W. L. DURRELL and R. S. KIRBY. Relation of the barberry to stem rust in Iowa. Iowa Agr. Exp. Sta. Res. Bull. 57 : 283-325. 1920.
142. MOREAU, M. F. Les maladies des céréales à la station de sélection de semences du massif Central en 1924. Rev. Path. vég. et Ent. agr. 12 : 31-37. 1925.
143. MORELAND, W. H. The relation of the weather to rust on cereals. Mem. Dept. Agr. India, Bot. Ser. 1 : 53-58. 1906.
144. MORRIS, H. E. and W. L. POPHAM. The barberry eradication campaign in Montana. Mont. Agr. Exp. Sta. Bull. 180. 1925.
145. MURPHY, P. A. (Discussion on dissemination of cereal rusts.) Proc. 5th Intern. Bot. Cong. Cambridge, 1930. 416-417. 1931.
146. NEWTON, MARGARET. The cereal rusts in Canada. Emp. Jour. Exp. Res. 6 : 125-140. 1938.
147. NEWTON, MARGARET and A. M. BROWN. Studies on the nature of disease resistance in cereals. I. The reactions to rust of mature and immature tissues. Can. Jour. Res. 11 : 564-581. 1934.
148. NEWTON, MARGARET and T. JOHNSON. Specialization and hybridization of wheat stem rust, *Puccinia graminis tritici*, in Canada. Canada Dept. Agr. Bull. 160. N.S. 1932.
149. PAMMEL, L. H. The barberry in Iowa and adjacent states. Proc. Iowa Acad. Sci. 26 : 193-237. 1919.
150. PELTIER, G. L. A study of the environmental conditions influencing the development of stem rust in the absence of an alternate host. I. The viability of the urediniospores of *Puccinia graminis tritici* form 3. Nebraska Agr. Exp. Sta. Res. Bull. 22. 1922.
151. PELTIER, G. L. A study of the environmental conditions influencing the development of stem rust in the absence of an alternate host. II. Infection studies with *Puccinia graminis tritici* form 3 and form 9. Nebraska Agr. Exp. Sta. Res. Bull. 25. 1923.
152. PELTIER, G. L. A study of the environmental conditions influencing the development of stem rust in the absence of an alternate host. III. Further studies on the viability of the urediniospores of *Puccinia graminis tritici*. Nebraska Agr. Exp. Sta. Res. Bull. 34. 1925.
153. PELTIER, G. L. A study of the environmental conditions influencing the development of stem rust in the absence of an alternate host. IV. Overwintering of urediniospores of *Puccinia graminis tritici*. Nebraska Agr. Exp. Sta. Res. Bull. 35. 1925.
154. PELTIER, G. L. A study of the environmental conditions influencing the development of stem rust in the absence of an alternate host. V. The period of initial infection of urediniospores of *Puccinia graminis tritici* on wheat. Nebraska Agr. Exp. Sta. Res. Bull. 35. 1925.
155. PELTIER, G. L. A study of the environmental conditions influencing the development of stem rust in the absence of an alternate host. VI. Influence of light on infection and subsequent development of urediniospores of *Puccinia graminis tritici* on wheat. Nebraska Agr. Exp. Sta. Res. Bull. 35. 1925.
156. PELTIER, G. L. Some aspects of the spread of stem rust. Centralbl. f. Bakt. II. 78 : 525-535. 1929.
157. PELTIER, G. L. Relation of weather to the prevalence of wheat stem rust in Nebraska. Jour. Agr. Res. 46 : 59-73. 1933.
158. PELTIER, G. L. and A. F. THIEL. Stem rust in Nebraska. Nebr. Agr. Exp. Sta. Res. Bull. 42. 1927.
159. PETERSON, R. F. Stomatal behaviour in relation to the breeding of wheat for resistance to stem rust. Sci. Agr. 12 : 155-173. 1931.

160. PETIT, A. De la transmission des rouilles des céréales en Tunisie. *Ann. du Service Bot. de Tunisie* 7 : 111-130. 1931.
161. PETIT, A. La transmission et le traitement des rouilles des céréales en Tunisie. *Ann. du Service Bot. Agron. de Tunisie* 9 : 201-218. 1932.
162. PETURSON, B. Epidemiology of cereal rusts. *In* Rept. of the Dominion Botanist for 1930: 44-46. Canada Dept. Agr. Ottawa. 1931.
163. PHILP, JAMES and A. G. SELIM. Rust-resistant wheats for Egypt. *Nature* 147 : 209. 1941.
164. POTENZA, G. Observations on the susceptibility of cereals to rust. *Abst. in Rev. Appl. Mycol.* 8 : 759-761. 1929.
165. PRITCHARD, F. J. A preliminary report on the yearly origin and dissemination of *Puccinia graminis*. *Bot. Gaz.* 52 : 169-192. 1911.
166. PROCTOR, B. E. The microbiology of the upper air. I. *Proc. Am. Acad. Arts, Sci.* 69 : 315-340. 1934.
167. PROCTOR, B. E. The microbiology of the upper air. II. *Jour. Bacteriology* 30 : 363-375. 1935.
168. RAEDER, J. M. and W. M. BEVER. Spore germination of *Puccinia glumarum* with notes on related species. *Phytopath.* 21 : 767-789. 1931.
169. REDDY, W. F. Black stem rust situation in Michigan. *Mich. Quart. Bull. Agr. Exp. Sta.* 8 : 148-151. 1926.
170. ROUSSAKOV, L. F. Observations sur l'influence des conditions météorologiques sur le développement de la rouille des céréales. *Rept. Intern. Conf. Phytopath. and Econ. Ent., Holland, 1923.* 227-280. 1923.
171. ROUSSAKOV, L. F. Peculiarities of the microclimate in the midst of plants in connection with the development of cereal rusts. *Abst. in Rev. Appl. Mycol.* 4 : 471-473. 1925.
172. ROUSSAKOV, L. F. Some results of the survey of cereal rusts in 1922-1924. *Abst. in Rev. Appl. Mycol.* 5 : 724. 1926.
173. ROUSSAKOV, L. F. Cereal rust in the Far East according to the data obtained from an enquiry in 1925. *Abst. in Rev. Appl. Mycol.* 7 : 232-233. 1928.
174. ROUSSAKOV, L. F. and M. F. PANTCHENKO. Infection of 1290 pure lines of wheat with stem rust and conception of immunity in time. *Abst. in Rev. Appl. Mycol.* 8 : 362-363. 1929.
175. RUDORF, W. and MARIA JOB. Untersuchungen bezüglich der Spezialisierung von *Puccinia graminis tritici*, *Puccinia triticina* und *Puccinia glumarum tritici*, sowie über Resistenz und ihre Vererbung in verschiedenen Kreuzungen. *Zeitschr. f. Züchtung, A*, 19 : 333-365. 1934.
176. RUSSELL, H. L., F. B. MORRISON, and W. H. ERLING. Gleanings from Science. *Ann. Rept. Wisconsin Agr. Exp. Sta. Bull.* 388. 1926.
177. SAVULESCU, T. Rumania: Black rust of cereals in 1932 and measures taken to prevent future outbreaks. *Intern. Rev. Agr.* 24 : No. 2. (Plant Protection) 29-31. 1933.
178. SAVULESCU, T. Beitrag zur Kenntnis der Biologie der Puccinia-Arten, die den Weizen in Rumanien befallen. *Zeitschr. f. Pflanzenkrank. u. Pflanzenschutz.* 43 : 577-594. 1933.
179. SAVULESCU, T. The problem of wheat rusts in Rumania in its relation to Central Europe. *Abst. in Rev. Appl. Mycol.* 17 : 510-511. 1938.
180. SCHAFFNIT, E. Studien über den Einfluss niederer Temperaturen auf die pflanzliche Zelle. *Mitt. Kaiser-Wilhelm Inst. f. Landw. Bromberg* 3 : 93-144. 1910.
181. SCHEIBE, A. Die Schwarzrostepidemie auf dem Balkan 1932. *Nachrichtenbl. Deutsch Pflanzenschutzdienst* 13 : 5-6. 1933.
182. SCHILBERSZKY, K. Der Berberitzenstrauch und die Schwarzrostfrage. *Phytopath. Zeitschr.* 2 : 614-637. 1930.
183. SHITIKOVA-ROUSSAKOVA, A. On the question of how rust infection is introduced into the Amur Region. *Abst. in Rev. Appl. Mycol.* 7 : 233-235. 1928.
184. SIBILIA, C. Researches on cereal rusts. *Abst. in Rev. Appl. Mycol.* 8 : 162-163. 1929.

185. SIBILIA, C. The distribution of *Berberis* in Italy in relation to *Puccinia graminis* Pers. Abst. in Rev. Appl. Mycol. 16 : 89. 1937.
186. SIBILIA, C. Researches on cereal rusts. VII. The overwintering of *Puccinia graminis tritici* Erikss. & Henn. and *P. trititica* Erikss. in Italy. Abst. in Rev. Appl. Mycol. 16 : 593. 1937.
187. SIEMASZKO, W. Quelques observations sur les maladies des plantes en Pologne. Rev. Path. vég. Ent. agr. 20 : 139-147. 1933.
188. SORAUER, P. Vorarbeiten für eine internationale Statistik der Getreideroste. Zeitschr. f. Pflanzenkrankh. 19 : 193-286. 1909.
189. STAKMAN, E. C. The black stem rust and the barberry. U.S. Dept. Agr. Year Book, 1918. 75-100. 1919.
190. STAKMAN, E. C. Barberry eradication prevents black stem rust in Western Europe. U.S. Dept. Agr., Dept. Circ. 269. 1923.
191. STAKMAN, E. C. Destroy the common barberry. U.S. Dept. Agr. Farmers' Bull. 1058, 1919 and 1923.
192. STAKMAN, E. C. The dissemination of cereal rusts. Proc. 5th Intern. Bot. Cong., Cambridge, 1930. 411-413. 1931.
193. STAKMAN, E. C. Epidemiology of cereal rusts. Proc. 5th Pacific Sci. Cong., Victoria and Vancouver, Canada, 1933. 4 : 3177-3184. 1934.
194. STAKMAN, E. C. Stem rust of cereals. U.S. Dept. Agr., Plant Disease Reporter 19 : 153-154. 1935. (Mimeographed).
195. STAKMAN, E. C. The 1935 black stem rust epidemic. The Northwestern Miller 184 : 62. 1935.
196. STAKMAN, E. C. Preliminary data relating to the development of stem rust in 1937. U.S. Dept. Agr., Plant Dis. Repr. 21 : 238-239. 1937. (Mimeographed).
197. STAKMAN, E. C. Further estimates on probable stem rust damage this year. U.S. Dept. Agr., Plant Disease Reporter 22 : 336-337. 1938. (Mimeographed).
198. STAKMAN, E. C. Wind dissemination of plant pathogens. Proc. 3rd Intern. Cong. Microbiol., New York, 1939. 272-273. 1940.
199. STAKMAN, E. C., W. T. BUTLER, R. U. COTTER, and J. J. CHRISTENSEN. The epidemiology of stem rust of wheat in three successive contrasting years. Phytopath. 28 : 20. 1938.
200. STAKMAN, E. C. and R. C. CASSELL. The increase and importance of Race 56 of *Puccinia graminis tritici*. Phytopath. 28 : 20. 1938.
201. STAKMAN, E., R. C. CASSELL, and W. Q. LOEGERING. Population trends of physiologic races of *Puccinia graminis tritici* in the United States from 1930 to 1939. Phytopath. 30 : 22-23. 1940.
202. STAKMAN, E. C. and L. H. HAMILTON. Stem rust in 1938. U.S. Dept. Agr., Plant Dis. Repr. Suppl. 117 : 69-83. 1939. (Mimeographed).
203. STAKMAN, E. C., A. W. HENRY, G. C. CURRAN, and W. N. CHRISTOPHER. Spores in the upper air. Jour. Agr. Res. 24 : 599-605. 1923.
204. STAKMAN, E. C., LEE HINES, R. C. CASSELL, and M. N. LEVINE. Population trends of physiologic forms of *Puccinia graminis tritici*, 1930 to 1934. Phytopath. 25 : 34. 1935.
205. STAKMAN, E. C., F. E. KEMPTON, and L. D. HUTTON. The common barberry and black stem rust. U.S. Dept. Agr. Farmers' Bull. 1544. 1927.
206. STAKMAN, E. C., R. S. KIRBY, and A. F. THIEL. The regional occurrence of *Puccinia graminis* on barberry. Phytopath. 11 : 39-40. 1921.
207. STAKMAN, E. C. and E. B. LAMBERT. The relation of temperature during the growing season in the spring wheat area of the United States to the occurrence of stem-rust epidemics. Phytopath. 18 : 369-374. 1928.

208. STAKMAN, E. C., and M. N. LEVINE. Effect of certain ecological factors on the morphology of the urediniospores of *Puccinia graminis*. Jour. Agr. Res. 16 : 43-77. 1919.
209. STAKMAN, E. C., M. N. LEVINE, and J. M. WALLACE. The value of physiologic-form surveys in the study of the epidemiology of stem rust. Phytopath. 19 : 951-959. 1929.
210. STAKMAN, E. C. and W. Q. LOEGERING. Physiologic races of *Puccinia graminis* in the United States in 1939. Paper No. 1840 of Sci. Jour. Series, Minn. Agr. Exp. Sta. Issued by U.S. Dept. Agr. Jan. 1941.
211. STAKMAN, E. C., L. W. MELANDER, and D. G. FLETCHER. Barberry eradication pays. Minnesota Dept. Agr. Bull. 55. 1927.
212. STAKMAN, E. C. and F. J. PIEMEISEL. Biologic forms of *Puccinia graminis* on cereals and grasses. Jour. Agr. Res. 10 : 429-495. 1917.
213. STAKMAN, E. C., W. L. POPHAM, and R. C. CASSELL. Observations on stem-rust epidemiology in Mexico. Phytopath. 29 : 22. 1939; Amer. Jour. Bot. 27 : 90-99. 1940.

ERRATUM¹

Insert as page 401A in Scientific Agriculture, Vol. 25, No. 6, February, 1945.

CRAIGIE—STEM RUST IN WESTERN CANADA

214. STOCK, F. Untersuchungen über Keimung und Keimschlauchwachstum der Uredosporen einiger Getreideroste. *Phytopath. Zeitschr.* 3 : 231-279. 1931.
215. TEHON, L. R. and P. A. YOUNG. Notes on climatic conditions influencing the 1923 epidemic of stem rust on wheat in Illinois. *Phytopath.* 14 : 94-100. 1924.
216. THOMSON, W. A. Soil temperatures at Winnipeg, Manitoba. *Sci. Agr.* 15 : 209-217. 1934.
217. THOROLD, C. A. Diseases of cereal crops in Kenya Colony. Colony and Protectorate of Kenya. Dept. Agr. Bull. 2. 1935.
218. TIEMANN. Kurze Betrachtung zum Rostbefall des Weizens in Schlesien im Jahre 1932. *Mitt. Deutsch. Landw. Ges.* 48 : 7-8. 1933.
219. TULL, JETHRO. Horse hoeing husbandry. pp. 1-332. John M. Cobbett, London, 1822.
220. UKKELBERG, H. G. The rate of fall of spores in relation to the epidemiology of black stem rust. *Bull. Torrey Bot. Club* 60 : 211-228. 1933.
221. VALLEGA, J. Especificación fisiológica de *Puccinia graminis tritici* en la Argentina, Chile y Uruguay. *Rev. Argentina Agron.* 7 : 196-220. 1940.
222. VASEY, A. J., J. G. BALDWIN, and A. C. DOERY. Stem rust at Warribee. Its incidence during 1934. *Jour. Dept. Agr. Victoria* 33 : 185-187. 1935.
223. VERVOERD, L. A review of the black stem rust (*Puccinia graminis* Pers.) situation, with special reference to the experimental methods applied to rust research in the United States of America and Canada, and the nature of the problem in South Africa. *South Africa Dept. Agr. Sci. Bull.* 138. 1935.
224. WALDRON, L. R. The black stem rust epidemic in 1935. The Millers' National Federation, Chicago, Aug. 16, 1935.
225. WALDRON, L. R. Stem rust epidemics and wheat breeding. *North Dakota Agr. Exp. Sta. & Col. Circ.* 57. 1935.
226. WALLACE, J. M. Physiologic specialization as a factor in the epidemiology of *Puccinia graminis tritici*. *Phytopath.* 22 : 105-142. 1932.
227. WALSTER, H. L. Rust and the weather. *Science* 53 : 346. 1921.
228. WARD, H. M. Researches on the life-history of *Hemileia vastatrix*, the fungus of the "coffee-leaf disease." *Jour. Linn. Soc. Bot.* 19 : 299-335. 1882.
229. WATERHOUSE, W. L. A note on the over-summering of wheat rust in Australia. *Agr. Gaz. New South Wales* 31 : 165-166. 1920.
230. WATERHOUSE, W. L. Australian rust studies: I. *Proc. Linn. Soc. New South Wales* 54 : 615-680. 1929.
231. WATERHOUSE, W. L. Australian rust studies. IV. Natural infection of barberries by black stem rust in Australia. *Proc. Linn. Soc. New South Wales* 59 : 16-18. 1934.
232. WATERHOUSE, W. L. Some aspects of cereal rust problems in Australia. *Proc. 5th Pacific Sci. Cong., Victoria and Vancouver, Canada, 1933.* 4 : 3169-3176. 1934.
233. WESTON, W. A. R. DILLON. Observations on the bacterial and fungal flora of the upper air. *Trans. Brit. Mycol. Soc.* 14 : 111-117. 1929.
234. WESTON, W. A. R. DILLON. Effect of light on urediniospores of black stem rust of wheat, *Puccinia graminis tritici*. *Nature* 128 : 67-68. 1931.
235. WESTON, W. A. R. DILLON. III. Studies on the reaction of disease organisms to light. The reaction of disease organisms to certain wave-lengths in the visible and invisible spectrum. *Sci. Agr.* 12 : 352-356. 1932.
236. WILHELM, P. Studien zur Spezialisierungsweise des Weizengelbrostes, *Puccinia glumarum* f. sp. *tritici* (Schn. lt) Erikss. et Henn., und zur Keimungsphysiologie seiner Uredosporen. *Arb. Biol. Reich. f. Land-und Forst.* 19 : 95-135. 1931.
237. WÜTHRICH, E. Über die Entwicklung von Metallsalzen und Säuren auf Keimfähigkeit der Sporen einiger der verbreitetsten parasitischen Pilze unserer Kulturpflanzen. *Zeitschr. Pflanzenkrankh.* 2 : 81-94. 1892.
238. ZEKL, F. Ursachen des Weizen-Rostes. *Deutsche Landw. Presse* 61 : 397. 1934.
239. ZIMMERMANN, A. Sammelreferate über die Beziehungen zwischen Parasit und Wirtspflanze. II. Die Uredineen. *Centralbl. f. Bakt.* II. 65 : 311-418. 1925.
240. ZIMMERMANN, A. and G. SCHNEIDER. Bericht der Hauptsammelstelle Rostock für Pflanzenschutz im Mecklenburg im Jahre 1909. *Art. d. Landw. Versuchsstat. Rostock.* 1910.

¹ Additional references for the paper "Epidemiology of Stem Rust in Western Canada" by J. H. Craigie, published in *Scientific Agriculture*, Vol. 25, No. 6, February, 1945.

**BARLEY VS. WHEAT AS THE BASAL FEED IN THE
BACON HOG RATION¹**E. W. CRAMPTON² AND G. C. ASHTON³*Macdonald College (McGill University), P.Q.*

[Received for publication October 3, 1944]

Previous trials in this series of feeding tests designed to evaluate Canadian Western grains and elucidate the best methods of using them for bacon hog production have demonstrated that, unlike barley, wheat when used as the sole basal feed of the ration may be expected to cause a lowered carcass excellence sufficient to materially reduce the cash returns from the hogs. It seems probable however, that wheat might be incorporated in mixtures with barley with satisfactory results. The limit to which it might be so used is at present unknown.

There was also the possibility that the best use might be made of wheat by restricting it to a part of the feeding period. Whether this should be for the finishing period to make use of the high energy value of the wheat, or for the growing period to capitalize on its vitamin B content in stimulating large feed intake and early growth rate is likewise unknown.

It was to obtain information on these questions that the hereinafter reported feeding trials were carried out.

EXPERIMENTAL PROCEDURE

Sixty June-born Yorkshire pigs averaging 44 lb. were allotted at random to 10 feeding groups of 6 pigs each. A second replicate of 60 October-born pigs was started the following December, so that in all 120 pigs are represented in the data herein reported. Within each feeding group in each replicate, equal numbers of male and female pigs were used. All pigs were individually penned and fed.

On the weekly weigh day on which the pigs individually reached about 110 lb. in weight they were changed from the starting "A" ration to the finishing "B" ration. These rations differed only in that the protein-mineral supplement made up 15% of the "A" rations; and 10% in the "B" mixtures.

The protein-mineral supplement consisted of:

- 40% Meat meal—(55% protein).
- 25% Linseed oil meal.
- 15% Fish meal.
- 10% Feeding bone meal.
- 5% Ground limestone.
- 5% Fine salt.

¹ Contribution from the Faculty of Agriculture, McGill University, Macdonald College, Que., Canada. Journal Series No. 193.

² Professor of Animal Nutrition—Macdonald College, P.Q.

³ Assistant in Animal Nutrition—Macdonald College, P.Q.

To each 100 lb. of this supplement, 0.2 grams potassium iodide was added when mixed.

The final rations fed to the several experimental groups were prepared by combining the above supplement with the following basal feeds or feed mixtures.

<i>Lot</i>	<i>Basal Feed or Feed Mixture</i>
I	Wheat 50% + Oats 50%
II	Wheat 100% (No. 4 Northern)
III	Wheat 75% + Barley 25%
IV	Wheat 50% + Barley 50%
V	Wheat 25% + Barley 75%
VI	Barley 100% (No. 2 C.W.)
VII	Barley to 100 lb. weight followed by Wheat to market weight.
VIII	Barley to 150 lb. weight followed by Wheat to market weight.
IX	Wheat to 100 lb. weight followed by Barley to market weight.
X	Wheat to 150 lb. weight followed by Barley to market weight.

All pigs until they weighed 110 lb. received daily 15 cc. of feeding fish oil of 2000 A and 400 D potency. The starting (A) rations were fed three times and the (B) rations twice daily in amounts limited by the pigs' appetites. Actual feeding was done by placing the allowance of meal mixture for each pig in his feeding trough and pouring over it about three times its weight of water.

As the pigs individually reached market weight they were slaughtered and the carcasses examined by Dominion Government Hog Graders according to the scheme of scoring employed for pigs on Advanced Registry test.

The design of the trial made possible a statistical analysis of the variance of the items of data according to the following scheme.

Source of Variance	Degrees of Freedom
All causes (120 pigs)	119
Between 40 sub-groups	39
Between 2 sexes	1
Between 2 seasons	1
Between 10 lots	9
Interaction (total)	28
Sex \times season	1
Lot \times sex	9
Lot \times sex	9
Lot \times sex \times season	9
Within sub-groups (error)	80

RESULTS

A summary of the general means of the important items of data recorded is given in Table 1 and will serve as a description of the typical pig in this test.

TABLE 1.—GENERAL MEANS OF WEIGHTS, GAINS AND FEED INTAKE

Item		Mean	Standard Deviation
		lb.	lb.
Initial wt.		43.6	10.9
Shipping wt.			
Males		200.0	5.64
Females		202.0	5.76
All		201.0	5.7
Gain			
A ration	Males	1.30	0.13
	Females	1.19	0.16
B ration	Males	1.70	0.23
	Females	1.51	0.20
Total period	Males	1.50	0.13
	Females	1.36	0.16
	All	1.43	0.15
Daily feed total period, all pigs		5.6	0.45

Other than for the fact that pigs averaged 44 lb. in weight at the start of these tests and that males and females were marketed at the same final weights the only matter of importance brought out in Table 1 is the highly significant difference in rates of gain between the sexes. This was evident from the first. Male pigs have gained from 10 to 15% faster, the greatest difference being during the fattening period.

This same fact may be shown in length of feeding periods needed to get pigs to market weight. Between the May-born and January-born groups there was no appreciable difference (111 vs. 113 days); but between males and females the difference was two full weeks (105 vs. 119 days). This was a greater difference than was found between any of the ration groups and illustrates the necessity for a consideration of sex difference in all pig feeding trials in which gain is one of the criteria of the effect of the experimental treatment.

It may also be pointed out that the females were slightly more variable in gains than the males. This was not enough to be a matter of importance in these tests, however.

In Table 2 the average data for the weights and gains of the pigs are shown according to the ration comparisons made. In so far as the live pig data are concerned, rate of gain and efficiency of ration in producing gain are the two most important items to be considered. With respect to

TABLE 2.—MEAN WEIGHTS, GAINS AND FEED INTAKE OF PIGS

Items	All pigs	I Wheat 50 + Oats 50	II Wheat 100	III Wheat 75 + Barley 25	IV Wheat 50 + Barley 50	V Wheat 25 + Barley 75	VI Barley 100	VII Barley to 100 lbs.	VIII Barley to 150 lbs.	IX Wheat to 100 lbs.	X Wheat to 150 lbs.	Necessary difference between lot means
Initial weights	43.6	44	45	43	45	44	44	44	42	44	43	2.0
Days fed	112	107	111	109	109	112	115	114	120	108	114	9.0
Final weights	201	202	201	201	200	201	198	204	202	201	200	5.0
Daily feed												
A period	4.2	4.5	4.2	4.1	4.1	4.1	4.2	4.2	4.1	4.2	4.0	0.32
B period	7.0	7.2	6.7	6.8	7.2	7.2	7.0	6.9	6.6	7.3	7.1	0.55
Total period	5.6	5.9	5.5	5.5	5.7	5.6	5.6	5.6	5.3	5.8	5.6	0.37
Daily gains												
A period	1.24	1.35	1.28	1.29	1.26	1.20	1.20	1.18	1.16	1.31	1.21	0.12
B period	1.61	1.65	1.59	1.68	1.65	1.65	1.55	1.59	1.55	1.60	1.58	0.18
Total period	1.43	1.51	1.43	1.47	1.46	1.41	1.37	1.41	1.35	1.45	1.39	0.12
Gains (total period) adjusted to aver- age feed	1.43	1.44	1.47	1.51	1.44	1.41	1.37	1.43	1.41	1.41	1.40	0.09

gain it is interesting to note that if the lots are ranked in order of their observed gains over the total period the first three were fed rations having 50% or 75% wheat.

It seems evident that any penalty in rate of gain due to barley is to be found chiefly during the growing period. Pigs started on wheat (Lots IX and X) made as rapid gains when finished on barley as pigs finishing on wheat after a slow start on barley (Lots VII and VIII). These differences in gains at the start of the feeding do not appear to be due to lack of palatability of the barley if the feed intake on the "A" ration is indicative. Indeed, excepting for the oats-wheat ration there is no evidence of a difference in feed intake traceable to kind of diet. The oats-wheat combination appeared to be particularly well liked by the pigs, though the efficiency of the ration was no better than the comparable barley-wheat mixture.

When the gains are adjusted (by regression) to those expected had all lots eaten the same (average) amounts of their respective rations it appears in general that ration efficiency declines as barley becomes more than 50% of the basal mixture; or as pigs are slowed up by starting on straight barley (then finished on wheat); or are finished on barley after starting on wheat. In terms of feeding period these differences are of the order of a week in time. The slowest group was in market at 27 weeks of age. Hence for practical purposes it might be considered that there was little difference between any of these 10 ration mixtures. This is in agreement with previous tests in this series, viz., that on the basis solely of gains and feed efficiency barley and wheat appear to be excellent hog feeds. The differences between them are much more apparent in their effects on the carcasses produced.

As already noted, the pigs of this trial were slaughtered and the carcasses examined by Dominion Hog Graders according to the plan followed for hogs of the Advanced Registry tests. Carcass grade is the rail grade on which the bonus payments are based. Carcass score is the basis of the qualification of sows in the Advanced Registry. Both are measures of carcass excellence for bacon production. Since they are not based on identical measurements, these two scores do not necessarily agree in all respects. Carcass score for example includes an actual measure of leanness. This is obtained after cutting the side. This cannot be done on sides to be processed for bacon. In general it may be said that the carcass grade is the more important from the practical feeders point of view, while the carcass score gives to the researcher the reason for the grades in that separate features of the carcass characteristics are more specifically measured.

From Table 3 it is evident that the chief effect of ration composition was in the extent of the development of the lean in the bacon rasher. In the barley-wheat mixture the area of the "pork chop muscle" of the rasher decreases steadily as more and more wheat replaces barley. The difference is probably of little practical importance when wheat constitutes up to 50% of the basal mixture. The wheat-oats combination also showed a small lean development as compared to the barley fed lots.

TABLE 3.—CARCASS MEASUREMENTS. EFFECT OF RATION

Item	I Wheat 50 + Oats 50	II Wheat 100	III Wheat 75 + Barley 25	IV Wheat 50 + Barley 50	V Wheat 25 + Barley 75	VI Barley 100	VII Barley to 100 lbs.	VIII Barley to 150 lbs.	IX Wheat to 100 lbs.	X Wheat to 150 lbs.	Necessary difference between lot means
Carcass wt. (lbs.)	152	153	149	151	152	148	153	153	150	151	4.0
Carcass length (ins.)	30.4	30.1	30.3	31.0	30.4	30.1	30.3	30.4	29.8	30.2	0.5
Shoulder fat (ins.)	1.7	1.7	1.7	1.7	1.7	1.7	1.6	1.6	1.7	1.6	0.2
Area, eye of lean (sq. ins.)	4.9	4.8	4.8	5.2	5.4	5.6	5.3	5.8	5.1	5.2	0.6
Per cent lean in rasher	39.3	38.9	40.6	42.4	43.8	43.8	40.1	43.6	42.9	42.6	3.3

The leanest carcasses of all, everything considered, were in: (1) the groups fed barley to 150 lb. and finished on wheat; (2) the 25% wheat—75% barley; and (3) those on straight barley. These pigs were among the more slowly gaining animals, and it is noteworthy that there was a statistically significant negative correlation between the area of the "eye of lean" and the daily gain to market weight. (See later).

Sex differences are marked in carcass characteristics, as shown in Table 4.

TABLE 4.—CARCASS MEASUREMENTS. EFFECT ON SEX.

Item	Males	Females	Necessary Difference
Carcass score (%)	70	81	4
Carcass wt. (lbs.)	151	152	2
Carcass length (ins.)	30.1	30.5	0.2
Depth shoulder fat (ins.)	1.8	1.6	0.1
Depth back fat (ins.)	1.2	1.0	0.06
Belly thickness (ins.)	0.8	0.7	0.06
Area eye of lean (sq. in.)	4.9	5.6	0.3
Per cent lean in rasher	39.1	44.5	1.5

There can be no doubt that at equal market weight (or carcass weights) the male pigs are fatter. This is the chief reason for the lower carcass score for males.

Carcass excellence for practical purposes is best indicated by the rail grading, since it is on this basis that bonus payments to the feeder are made. In connection with this index of excellence it must be remembered that it is subject to the personal factor, being the judgment of a grader. It is especially subject in these tests to variations resulting from the marketing of individual pigs at different times so that comparisons on the rail with other pigs of the test is not possible. Table 5 summarizes the grading records.

TABLE 5.—CARCASS GRADES

Grade	I Wheat 50 + Oats 50	II Wheat 100	III Wheat 75 + Barley 25	IV Wheat 50 + Barley 50	V Wheat 25 + Barley 75	VI Barley 100	VII Barley to 100 lbs.	VIII Barley to 150 lbs.	IX Wheat to 100 lbs.	X Wheat to 150 lbs.
Males										
A	3	1	0	2	1	5	3	0	1	3
B	3	5	6	3	5	1	3	5	4	3
C				1				1	1	
Females										
A	5	2	6	6	6	4	3	4	5	4
B	1	4	0	0	0	2	2	2	1	2
C										
All pigs										
A	8	3	6	8	7	9	6	4	6	7
B	4	9	6	3	5	3	5	7	5	5
C				1				1	1	

Perhaps the most striking feature of these data is the sex difference. It seems evident that at market weights of 200 lb. it is exceedingly difficult to produce on heavy wheat feeding male pigs which will bring bonuses for carcass excellence. The case of the females is sharply different, excepting possibly where barley is fed as the entire basal feed.

These sex differences alone are more clearly shown if presented irrespective of ration as follows:

Sex	Grade of Carcass			Total carcasses
	A	B	C	
Males	19	38	3	60
Females	45	14	0	59

It is difficult to know what this situation ultimately will mean. Must separate carcass standards for barrows and gilts be established?

It has already been shown at this station that some correction can be made by an adjustment in the marketing weights. Male pigs marketed 15 to 20 lb. lighter than the present accepted weight of 200 lb. results in an increase in the proportion of A grades. There is frequently a penalty in carcass score, however, for light weight carcasses. Type of pig, particularly with respect to length, is an important factor governing optimum marketing weights. Within a given type, there appears to be a difference in carcass characteristics of male and female pigs such that the latter are more suitable for high quality bacon as is it now graded.

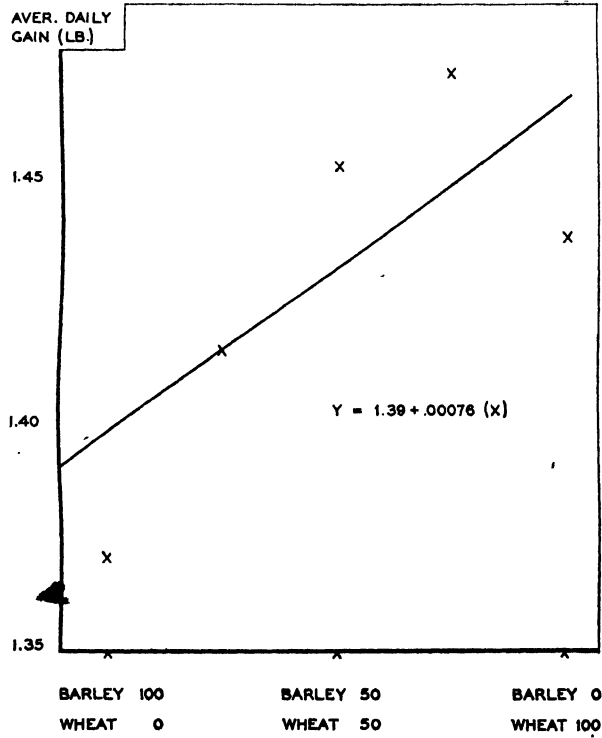


FIGURE 1

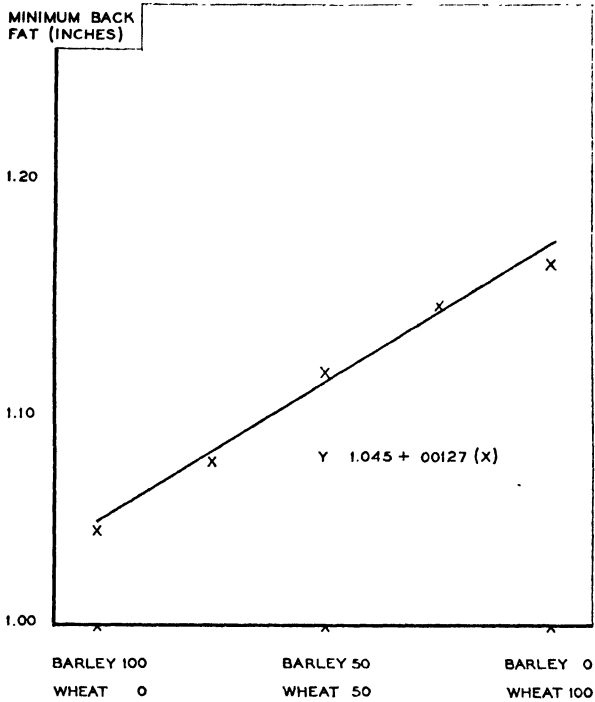


FIGURE 2

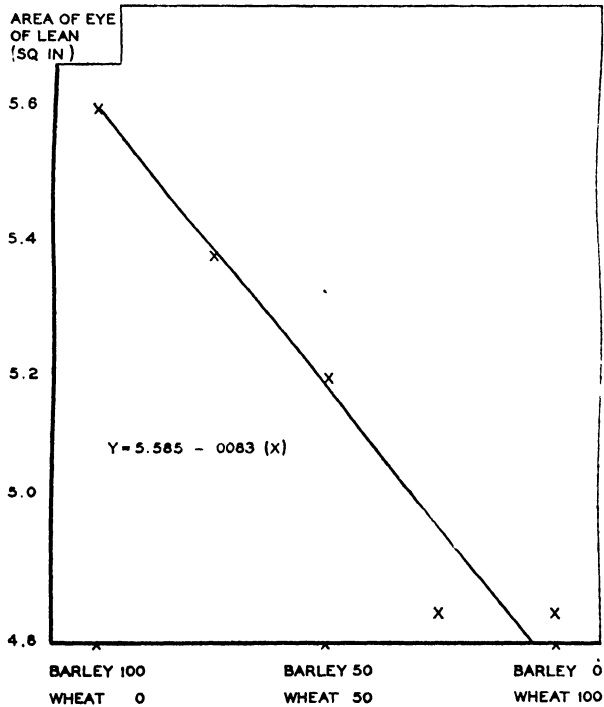


FIGURE 3

Some of the effects of replacing barley by wheat in the basal portion of the bacon hog ration are indicated by the data of Lots II to VI inclusive. Using the average values of each lot as single observations, simple regression coefficients were calculated showing for each replacement of 1% of barley with wheat the quantitative change in (1) rate of gain (lb.); (2) minimum back fat (in.); and (3) area of "pork chop muscle" in the rasher (sq. in). The regressions appear at first to be small, but it will be remembered that the effect of replacing half the barley with wheat for example, is 50 times the regression. The data are shown graphically in Figures 1 to 3.

There is no doubt that replacement of barley with wheat tends toward faster rates of gain and greater depth of fat on the carcass. The greater fatness is reflected also in a decrease in the amount of lean as measured by the area of the eye of lean of the pork chop muscle. Multiple correlation indicates that about 82% of the variability in the area of eye of lean is associated with rate of gain and with increased depth of the external fat layer.

The relation of rate of gain to the leanness of the bacon carcass is of some interest inasmuch as rate of gain may be affected by factors other than the introduction of wheat into the ration. Simple correlation between gains and "eye of lean" are statistically significant ($P .05$) not only because of type of ration but also between pigs on identical rations.

TABLE 6.—SIMPLE CORRELATIONS AND REGRESSIONS, BETWEEN AREA OF EYE OF LEAN (SQ. IN.) AND THE INDEPENDENT VARIABLE SHOWN.

Independent variable	Between lots		Between pigs within lots	
	<i>r</i>	<i>b</i>	<i>r</i>	<i>b</i>
Daily gain to 110 lbs.	-.85	-4.42	-.23	-1.15
Daily gain 110 lbs. to 200 lbs.	-.66	-4.65	-.30	-0.99
Daily gain weaning to market	-.87	-5.79	-.32	-1.54

This raises several practical problems in pig raising. Is it possible that older pigs can always be expected to have leaner carcasses than pigs that have made more rapid gains to the 200-lb. market weight? If so, why? In these trials neither rate of gain nor shipping age is significantly correlated with carcass score either between different rations or between pigs on identical rations. However, area of eye of lean was significantly correlated with shipping age between pigs on identical rations, *but not between rations*.

Can this effect be attained by the simple expedient of curtailing feed during the fattening period? Correspondence from McMeekin⁴ indicates this to be the case, and would appear to support the hypothesis that until the pig is about four months of age the growth made normally tends to consist principally of bone and muscle regardless of kind of ration. Full feeding during this time permits full and rapid development of these tissues. The succeeding growth, however, is normally one predominantly of fattening if liberal feed is available. Some frame and muscle growth still

⁴ Dr. C. P. McMeekin, Ruakura Animal Research Station, Hamilton, New Zealand. Correspondence to author, December 1943.

continued nevertheless, and under limited feeding this becomes a relatively larger part of the live weight gains. The end result in the 200-lb. pig should be a carcass of relatively greater leanness than that obtained from the pig that has been full fed during the fattening period.

The feeding trials herein reported yield no data from which the validity of this hypothesis can be judged, though the desirability of such information is obvious. (Tests of this hypothesis are now in progress at this station).

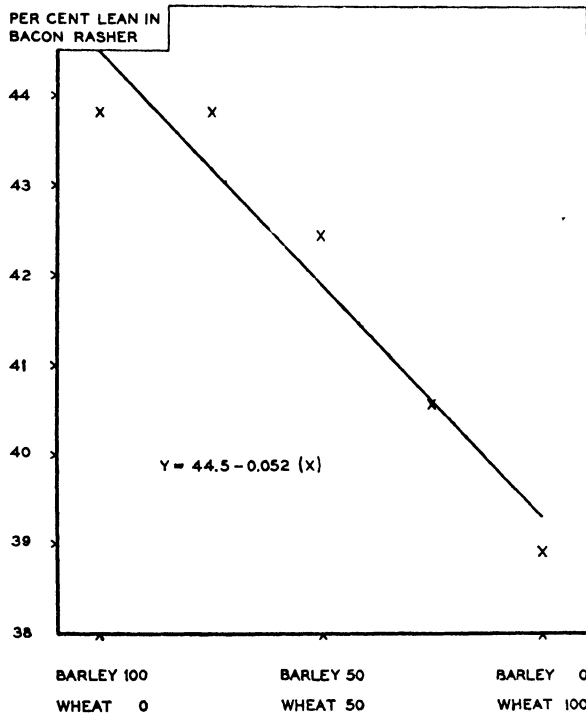


FIGURE 4

As to whether wheat is best used in the early part of the feeding period or in the final fattening period is not clearly indicated in these tests. No consistent significant trends or differences are apparent between these four lots in any respect. In actual gains for example the group fed wheat to 100 lb. and finished on barley stood first, followed by those fed barley to 100 lb. and finished on wheat. On the other hand feeding pigs on wheat to 150 lb. and finishing on barley stood above barley to 150 lb. with wheat finishing. About all that can be said from the figures available is that the pigs starting on barley until 150 lb. made the slowest gains of any of the 10 lots, but had carcasses showing a percentage lean comparable to those on pure barley or barley 75-wheat 25 mixture. These three lots ranked first in percentage lean (43.8; 43.8; and 43.6); followed by the two starting on wheat and finishing on barley, and the barley 50-wheat 50 mixture (42.9; 42.6; and 42.4). Barley to 100 lb. followed by wheat to finish and the barley 25-wheat 75 mixture was next (40.6; 40.1); and last were oats 50-wheat 50, and pure wheat (39.3; 38.9).

If these lots show anything at all it is merely confirmation of the evidence from the lots fed mixtures of barley and wheat that wheat in general tends to cause greater fattening rate and a decrease in the amount and porportion of lean tissue in the bacon hog carcass.

The wheat-oats mixture proved exceptionally palatable and rate of gain was the greatest of all lots in the trial. The carcass data, however, indicate that oats does not counteract the "wheat effect" on degree of fattening or lean development. Rail grade, which cannot include a direct observation of lean development, showed 66% bonus carcass for wheat-oats as compared to 66% for barley 50-wheat 50, and 75% for straight barley.

The reasons for the fattening effect of wheat may be several. The fibre content as compared to barley is smaller and fibre is largely indigestible by swine. Thus with equal quantities eaten, the wheat rations would contain more digestible nutrients than barley. This should mean faster gains.

On the other hand oats contain more fibre than barley. Nevertheless the pigs consuming the wheat 50-oat 50 mixtures gained more rapidly than did those on the wheat 50-barley 50 ration. It is true the wheat-oat group ate more feed—just enough more that the efficiency of the two rations was the same.

In view of the previous findings in this series of studies on wheat and barley concerning the effects of wheat germ on rate of fattening, and the known relation between thiamin and fat from carbohydrate, one wonders whether the fact that oats carries the highest thiamin content of all cereal grains with wheat next is not of significance.

CONCLUSIONS

The data from these feeding trials confirm previous findings in this series of studies on the value of coarse grain for bacon hog production to the effect that as compared to barley wheat tends to cause more rapid live weight gains, and on pigs marketed at 200 pounds results in fatter carcasses. The latter effect is sufficiently pronounced in rations containing over 50% wheat (in the basal portion) to be of practical significance in reducing the market returns.

Male pigs appear to be more subject to carcass damage from heavy wheat feeding than females, presumably because of more rapid maturing of the male sex.

There is evidence that leanness of the bacon rasher is correlated with rate of live weight gain to 200 lb. which suggests that restricting feed (i.e., total digestible nutrients) intake during the fattening period might result in leaner carcasses regardless of kind of ration.

ACKNOWLEDGMENT

It is a pleasure to acknowledge the continued interest in, and generous financial support of this series of studies on the feeding value of Western Canadian Grains by the Canadian Co-operative Wheat Producers Limited.

BLACK ROT OF RUTABAGAS

J. K. RICHARDSON

Dominion Laboratory of Plant Pathology, St. Catharines, Ontario

[Received for publication December 5, 1944]

Black rot of table rutabagas has been increasing in severity since 1940 in many sections of Ontario, necessitating a study of the problem to formulate recommendations in an endeavour to bring the disease under control.

Since little information was available concerning black rot on this particular host, much preliminary investigation was necessary to ascertain fundamental information before specific phases of the problem could be studied. The present paper will give some idea of the information already obtained, with recommendations suggested to assist in bringing the disease under control.

HISTORY AND DISTRIBUTION

Black rot of cruciferous plants was one of the earliest discovered bacterial diseases of plants, being first described on cabbages by Garman in 1891 (4). Two years later Pammel (5) published one of the first reports of the disease on rutabagas and turnips. Since that time there have been many records in the literature of various etiologic, ecologic and economic phases of the disease on other cruciferous hosts.

The disease was reported on rutabagas in Ontario in 1907 (2) and appears to be present wherever crucifers are grown. Although present in Ontario for years, it did not become of significant economic importance until 1939-1940. The severity and amount of the disease varies in different districts throughout the province, but being present in all, is annually a potential menace to the crop. Although black rot is present in Quebec and the Maritime Provinces, it is apparently of little economic importance there. The disease situation in the Western Provinces is not known.

SYMPTOMS OF THE DISEASE

The earliest visible symptom on the leaves is the appearance of small water-soaked areas most frequently along the margin at the terminus of a vein, but under optimum conditions for infection, on any part of the leaf. As the water-soaked areas enlarge, they turn yellow and the earliest infected portions die making yellow bordered lesions of necrotic tissue, in which the small veins are characteristically dark brown to black in colour (Figure 2B). When originating on the edges of the leaves the lesions are roughly triangular in shape with the apex toward the leaf base, infections increase in size, several may coalesce, and progress towards the midrib then down the leaf which eventually dies and falls from the plant.

Although black rot infected leaves become chlorotic, all chlorotic leaves are not necessarily infected with the disease since chlorosis and defoliation may result from unfavourable environmental conditions. If

¹ Contribution No. 800 from the Division of Botany and Plant Pathology, Science Service, Department of Agriculture, Ottawa, Canada.

² Assistant Plant Pathologist.

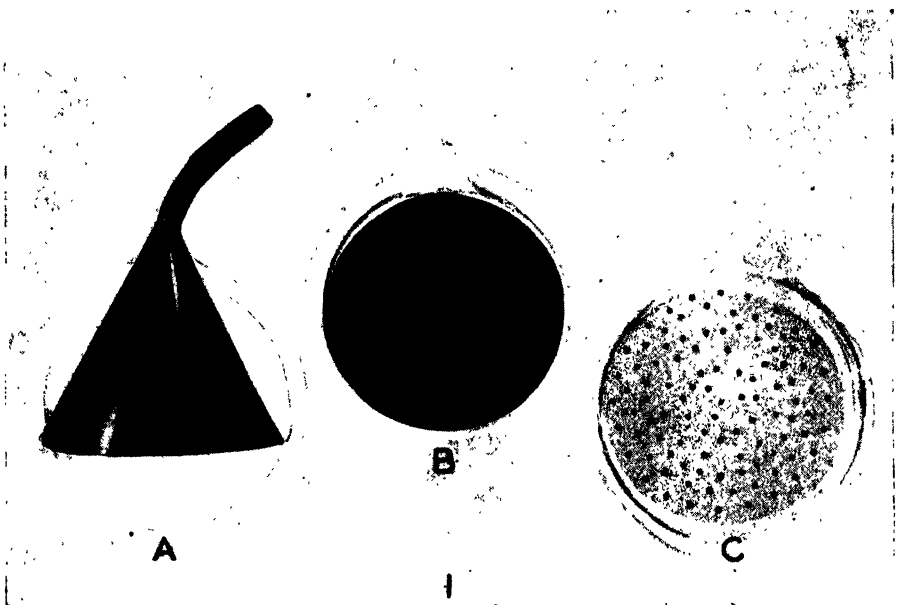


FIGURE 1. A, suction seed counter; B, base of cone showing 100 holes; and C, seeds in culture dish as placed by counter.

black rot is the causal factor, partially dead leaves will have chlorotic areas separating healthy and necrotic tissues and the characteristic dark veining.

In black rot infected fields where leaf spots caused by *Alternaria* or *Cercospora* spp. are present, black rot has often been observed associated with the fungus lesions. In these cases, the necrotic area is usually regular in outline, lighter in colour and more papery in appearance, but having the characteristic yellow margins of typical black rot lesions.

Symptoms in the roots are a blackening of the vascular tissue first in localized areas of the vascular ring just beneath the cortical layer (Figure 7) and in severe cases scattered throughout the body of the root (Figure 9). Since the infection usually enters the root from the top through the vascular connections with infected leaves, the amount of discoloration is largely dependent on the severity of leaf infection. The blackening occurs first in the crown, later following the vascular strands to the base of the root (Figure 8). If infection enters from the soil, as sometimes occurs, the blackening progresses upwards instead of downwards. The disease progresses

FIGURE 2. A, Healthy leaf and B, leaf showing typical symptoms of black rot. Note dark veins in chlorotic areas.

FIGURE 3 AND 4. Seedlings three weeks old showing black rot infection on all cotyledons (chlorotic and necrotic areas). Slightly further advanced in 3 than in 4.

FIGURE 5. Healthy seedling, same age as in Figure 3 and 4.

FIGURE 6. Seedlings grown from artificially inoculated seed, A, disinfected with Semesan before planting and B, not disinfected.



during the post-harvest period at a rate varying with the severity of infection and with the storage environment, until the root becomes partially or wholly pervaded by a spongy dry rot (Figure 10).

When seed is infected, and young plants are not killed before emergence, either one or both of the cotyledons will show the disease at about the time the second leaves have developed. The symptoms appear as a marginal chlorosis, and then necrosis, usually in the apical indentation at the end of the main veins (Figures 3 and 4). Infected cotyledons die prematurely, stunt the seedling's growth (compare Figures 4 and 5), and the disease spreads to the new leaves as they develop.

THE PATHOGEN

Black rot of rutabagas is caused by the bacterial plant pathogen *Xanthomonas campestris* (Pamm.) Dowson, the etiological and ecological relations of which have been thoroughly dealt with on many cruciferous hosts (3 and 6). The causal organism can be readily isolated from diseased leaf or root tissue and will remain viable and retain its pathogenicity for considerable time. The organism was still pathogenic after storage for a year at 35° to 40° F., but remained viable for only four to five months at room temperature.

Throughout the progress of these investigations, the presence of the disease has been established by isolation and culture of the organism, and confirmed by symptom expression on and re-isolation from artificially inoculated leaves of young swede turnip plants.

EXPERIMENTAL

Seed Transmission of the Disease

It has been proved that black rot can be seed transmitted and that the pathogen can live on cabbage and Brussel sprouts seed for at least 3 years (1). During the years 1939-1942 when black rot was increasing in Ontario, the acreage planted to the recently introduced Laurentian variety was increasing to such an extent that all available seed was being planted the spring after it was grown. It was thought that much of the disease may have been introduced on this fresh seed. Accordingly, commercial seed was obtained from as many sources as possible and tested for the presence of the pathogen; 500 to 800 seeds from each sample were counted and plated on potato dextrose agar jelly with the suction counter illustrated in Figure 1. All bacteria which developed from the seeds were isolated and cultured and those which resembled the pathogen were used for artificial inoculations to determine their pathogenicity. Up to and including November 30, 1943, sixty-five samples were tested. From the 35,700 seeds plated, 5,236 isolations were made, a number of which were pathogenic. In the samples tested the seeds infected varied from 0 to 6%.



FIGURE 7. Primary symptoms of black rot.

FIGURE 8. Black rot inside the cortical tissues of the root resulting from an infection similar to that shown in Figure 7.

FIGURE 9. Severely infected root as it appears at harvest time.

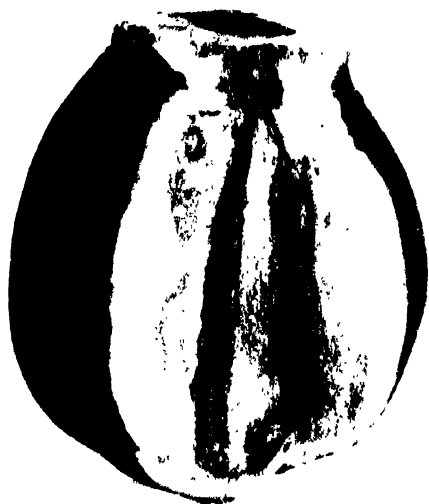
FIGURE 10. Severely infected root after five months in storage. Note the dry spongy nature of the decay.



7



9



8



10

In a test conducted with 12 seed plants grown from black rot infected roots, although the disease was sufficiently severe to rot many of the stalks prior to blossoming and seed formation, *X. campestris* could not be isolated from any stalk at a distance greater than 7 inches from the infected root and in a number of cases the pathogen did not ascend the stalk more than 1 inch; 500 seeds from each plant were plated, but in no case was the pathogen recovered.

Viability of Pathogen on the Seed

Since *X. campestris* is present on the seed, it seemed desirable to obtain some information on the length of time the pathogen would remain viable following natural and artificial contamination. In the seed tested, 56% of the samples harvested in 1942, 33 from 1941, and a single sample from 1940, contained seeds from which *X. campestris* was isolated.

One sample of 1942 grown seed showed 3.4% infected seed on May 18, 1943, but when retested on November 3 after having been stored in the laboratory during the intervening 24 weeks, showed only 0.2% infection. The fact that infection decreases with the ageing of the turnip seed may explain, in a measure, the correlation between the shortage of seed stocks and the increase of black rot in Ontario in recent years.

On a number of occasions, samples of clean seed were inoculated with water suspensions of *X. campestris*, dried at room temperature, and stored in various environments. Periodic isolations from this seed recovered the pathogen in one case 4 months after inoculation, but viability decreased very rapidly after 2 months. Whatever the explanation, it is quite evident that the pathogen remains viable for much longer periods on naturally contaminated seed.

Seed Disinfection

Although it is realized that treatment with hot water is probably the most effective method of killing black rot bacteria associated with the seed, the difficulties involved in its use make it unsatisfactory as a general recommendation.

Tests were conducted with two objects in view; first, to find a disinfectant that was relatively simple to apply and capable of killing the pathogenic bacteria; and second, one that in addition to being effective, could be applied to the seed at its source before packaging, to relieve growers of the necessity of treating their own seed. In the latter case, the possible detrimental effect on the seed when treated several months in advance of planting, had to be determined.

All tests on the efficacy of the various disinfectants were made with seed artificially inoculated by soaking for 10 minutes in a water suspension of *X. campestris*, dried at room temperature, disinfected the following day and planted in flats of steamed soil. The number of diseased seedlings appearing in the flats was taken as an index of the efficiency of the chemical tested.

The effect of the disinfectant on the viability of the seed was recorded by germination tests on filter paper.

In the following table, the control obtained by the disinfectants mentioned is recorded as the average of five separate tests with 200 seeds each.

TABLE 1.—PERCENTAGE GERMINATION AND AMOUNT OF DISEASE IN ARTIFICIALLY INOCULATED SEED TREATED WITH VARIOUS DISINFECTANTS, AND EFFECT OF DISINFECTANTS ON GERMINATION

Disinfectant	Germination	Black Rot	Germination of non-inoculated seed stored in paper bags after disinfection		
			2 days	8 months	17 months
	%	%	%	%	%
HgCl ² 1/1000	92	0.32			
Semesan	89.30	1.34	98.5	99.0	95.0
Ceresan	57.50	1.22	86.5	67.5*	52.0†
Zinc oxide	94.60	1.90	97.0	96.0	94.0
Spergon	93.50	2.14	97.0	97.5	100.0
Cuprocide	91.80	1.63	99.5	99.5	99.0
Thiosan	93.90	12.14	97.0	96.5	94.5
Arasan	93.55	16.71	91.0	95.0	91.5
Fermate	92.60	21.06	97.5	98.5	97.5
None	91.40	46.17	98.5	99.5	98.5
Not inoculated	93.70	0.00	98.0	99.0	97.5

* 10 weeks.

† 11.5 months.

Soil Transmission of the Disease

It has been proved that the disease can be initiated by the planting of infected seed and it is also known that the spread from leaf to leaf and thence to the root takes place quite rapidly under warm humid conditions. The possibility of infection from the soil however, though suggested in some cases, had not been definitely established. To prove this point, steam sterilized soil was inoculated with a quantity of finely ground infected swede turnip roots, then planted with seedlings of Essex Rape, and Purple King and Laurentian swede turnip on November 24, 1942.

During the five months the plants remained in the soil, there was some variation in their rate of growth and a number of the plants developed typical black rot lesions on some of their leaves. When harvested, all roots were pulled and sliced horizontally every quarter inch to determine if the disease was present and whether the infection had progressed upwards or downwards in the root. This could be quite readily determined by comparing the intensity of the vascular discoloration in successive slices.

TABLE 2.—PERCENTAGE OCCURRENCE OF TYPES OF INFECTION OF ROOTS OF CRUCIFEROUS PLANTS GROWING IN ARTIFICIALLY INOCULATED SOIL

Crop	Healthy roots	Infection upwards through root	Infection downwards through crown	Infection in both directions
Rape	75.0	10.7	3.6	10.7
Purple King	25.0	25.0	0.0	50.0
Laurentian	7.1	64.3	10.7	17.9

It was also demonstrated that similar infection will occur after a water suspension of a pure culture of the pathogen has been added to the soil in which young seedlings were planted.

This clearly demonstrates that the presence of the pathogen in the soil can be a potential source of infection to the crop.

Field Experiments and observations during the 1943 Growing Season

There was extremely heavy and frequent precipitation during the early part of the season with the result that most fields were sown considerably later than usual and many had to be resown because of heavy rains, immediately following sowing. However, subsequent environmental conditions were ideal for rapid growth during the early summer, but later in the season growth was arrested by drought, resulting in lack of size in many of the late sowings.

At regular intervals during the growing season, surveys of several of the largest producing areas were made in order to check on the general black rot situation, to compare fields planted with disinfected and untreated seed and to obtain information on disease spread and other factors relating to the problem.

Six lots of seed were treated at the laboratory and planted by farmers in various districts. All other disinfections were done by the individual growers themselves according to recommendations contained in a circular distributed from this laboratory, but no check was made on the accuracy of the methods employed.

Although there were a number of fields planted with untreated seed which showed very little black rot and some fields planted with disinfected seed which showed a comparatively high disease content, by and large, fields planted with disinfected seed had a more even stand, were more vigorous, and had appreciably less disease than those where untreated seed was used.

Twenty fields planted with seed disinfected with either Semesan or mercuric chloride, and 12 planted with untreated seed were critically examined with results as shown in the following table.

TABLE 3.—A COMPARISON OF THE AMOUNT OF BLACK ROT IN FIELDS PLANTED WITH DISINFECTED AND UNTREATED SEED

Amount of Disease	Disinfected Seed	Untreated Seed
None	2	0
Trace	15	2
Slight	2	3
Moderate	1	1
Severe	0	6

There were no marketable rutabagas from three of the six severely diseased fields planted with untreated seed, while in the remaining three only part was saleable.

The fact, already shown, that different samples of seed vary greatly in their disease content, may readily explain the variation in the amount

of disease in fields planted with untreated seed. Although there is no way of determining the origin of infections responsible for the disease in fields planted with disinfected seed, any one or a combination of three factors may have a bearing on the condition. First, seed disinfection is seldom perfect, and since some 190,000 seeds are sown on every acre, it is quite possible that the disease might originate from the few imperfectly disinfected seeds that produce diseased plants. There is also the possibility of infection from the soil or from other cruciferous plants in close proximity to the fields.

It was apparent that under favourable environmental conditions the disease can spread very rapidly through fields by splashing of rain, insect transmission, and working in the crop when the foliage is not dry. Many diseased fields revealed the presence of definite infection centres, generally located along surface washes or in depressions where the ground remained moist for considerable periods and from which the disease radiated.

Humid conditions are essential for the spread of the disease because although there was a rapid increase in its incidence during early summer, little or no spread took place, even in severely infected fields, in late summer and early fall when drier conditions prevailed.

Field observations during the 1944 Season

The beneficial results obtained from the use of disinfected seed in 1943 were so striking that growers and distributors were convinced that nothing but treated seed should be planted.

As a result it is estimated that over 95% of the seed planted in 1944 was disinfected either before packaging, by distributors, or before being sown, by the growers themselves. In most of the commercial disinfection, Semesan was used but some Arasan treated seed also reached the market.

Although weather conditions were favourable for the development of black rot, especially in the late summer and fall, the disease was of little economic importance where Semesan or mercuric chloride disinfected seed was used. However, in a number of instances where untreated seed was planted the disease was severe.

CONTROL OF THE DISEASE

Although there are still many phases of the black rot problem on which there is no information available, and repetition of many of the tests herein described would greatly increase their value, nevertheless from the information accumulated to date, it is possible to formulate certain control recommendations that should aid materially in the reduction of the disease in this province.

Never plant untreated seed. If it has not been disinfected before reaching the retail market, it should be treated by the grower before planting with either Semesan powder or a liquid solution of mercuric chloride (corrosive sublimate). If Semesan is used, half fill a screw capped container with seed and add the recommended quantity of disinfectant. Shake the contents vigorously until every seed is thoroughly coated with the powder, then screen off the excess before sowing the seed. It is beneficial to treat well in advance of planting, wrapping disinfected seed in a clean paper

bag, not the original container, until ready to use. When treating with corrosive sublimate, make a water solution 1-1000 (1 tablet in a pint of water) in a non-metallic container. Place the seed loosely in a porous cotton or cheesecloth bag and soak in the solution for 20 minutes, keeping the seed immersed at all times by prodding with a blunt stick. Remove seed from the bag and dry as rapidly as possible. Best results will be obtained if seed is sown as soon as it will flow freely. Utmost care should be used in handling all disinfectants for they are deadly poisonous.

Practise at least a 4-year rotation and do not plant rutabagas in the same field or immediately adjacent to one which grew a cruciferous crop the previous year.

If possible, it is advisable to plant in a well drained field where there is little surface washing and few depressions where water is liable to collect and the soil remain soaked for any length of time, particularly if the surface drainage comes from farm buildings or a field previously infected with black rot.

When cleaning out the root cellar, never put refuse on the manure or compost pile where it could be again returned to the land; and after the removal of debris, all walls, floor and ceiling should be disinfected by thoroughly spraying with a solution of bluestone (copper sulphate) 1 lb. in 10 gallons water, or formalin, 1 pint in 6 gallons water.

If a field of rutabagas becomes severely infected with black rot just before harvest time, it is advisable to dispose of the crop for immediate consumption, since in a comparatively short time the disease can infect the roots sufficiently to impair their market value seriously. Roots from a diseased field should never be placed in storage for future shipment because the disease is sure to cause severe loss by spreading through the stored stock.

SUMMARY

Black rot of rutabagas has been increasing in Ontario since 1939, resulting in severe losses to many producers. The rapid increase in popularity of the Laurentian variety, necessitating the use of fresh seed, may have considerable bearing on the situation.

The symptoms of black rot, which affects cruciferous hosts generally, are characteristic and not easily confused with other leaf and root diseases, the pathogen *Xanthomonas campestris* is a seed borne vascular parasite, quite readily isolated and cultured.

Chemical seed disinfectants vary in their lethal effects upon the pathogen. Mercuric chloride and Semesan have given the most satisfactory results.

Infection may enter the plant through the leaves, or from the soil through the roots and under humid conditions spreads very rapidly.

In 1943 striking reductions in the amount of black rot were noted in fields planted with disinfected seed, and in 1944 when over 95% of the seed was disinfected the disease was not of economic importance.

Recommendations for controlling the disease are outlined.

ACKNOWLEDGMENT

Sincere thanks are accorded Dr. G. H. Berkeley for his keen interest and helpful suggestions throughout the progress of this investigation.

REFERENCES

1. CLAYTON, E. E. Second progress report of black rot investigations, Long Island. *Phytopath*, 15 : 48-49. 1925.
2. EDWARDS, S. F. *Pseudomonas campestris*. Thirty-second Ann. Rept. Ontario Agri. College and Exp. Farm for 1907 : 134. 1908.
3. ELLIOTT, CHARLOTTE. Manual of Bacterial Plant Pathogens. The Williams & Wilkins Company, Baltimore. 1930.
4. GARMAN, H. A bacterial disease of cabbages. *Bot. Gaz.* 16 : 265. 1891.
5. PAMMEL, L. H. Preliminary report on a rutabaga and turnip rot. *Bot. Gaz.* 18 : 27. 1893.
6. SMITH, ERWIN F. An Introduction to Bacterial Diseases of Plants. W. B. Saunders Company. Philadelphia and London. 1920.

SHATTERING IN OATS¹

R. A. DERICK AND D. G. HAMILTON²

Central Experimental Farm, Ottawa, Ontario

[Received for publication December 29, 1944]

The more extensive use of the combine has created a greater interest in varieties that will withstand weather conditions that favour shattering. In the case of oats, the comparatively loose attachment of the spikelets favours shattering when an over mature crop is subjected to high winds, rain, hail or even ordinary handling. In studying the question of varietal resistance to shattering in oats at Ottawa over a period of two years, data have been collected which may be of interest to those working with this crop.

Very little investigational work has apparently been done on shattering in oats and only one reference has come to the notice of the writer, i.e., "Experimentelle Untersuchungen uber des Ausfallen der Korner bei Hafer und Weizen", by F. Priebs, in Bot. Archiv. 27 ; 1-59, 1929. This paper deals with the problem of shattering in oats, first in relation to the effect of weather and second on the influence of spikelet attachment. The data were obtained by using two methods of artificial shattering, i.e., the "drop" and the "shake" methods. In the former the panicles were dropped from a distance of 90 cm. 8 times, and in the latter the panicles were subjected to horizontal shaking covering a distance of 46 mm. for 90 seconds or 375 times. Apparently weather conditions during the growing season are associated with shattering in oats, and the work reported by Priebs shows that high precipitation during the period of greatest growth causes more shattering.

A further effect of high precipitation during this period is that it hinders the development of sclerenchyma tissue at the point of spikelet attachment therefore increasing the tendency to shatter. In dealing with the spikelet attachment this author states that the size of peduncle base, and the angle of spikelet attachment are directly associated with shattering. The larger the peduncle base and the closer the approach to a right angle spikelet base, the greater the resistance to shattering.

MATERIALS AND METHODS

The object of the work on this problem at Ottawa has been to determine whether varieties differ in shattering tendencies and to make use of such findings in the oat breeding program. On account of the difficulties of studying shattering under natural conditions, an effort was made to use machine shaking as an index to varietal resistance, although both methods have been used in accumulating the data presented below.

In 1941 eight varieties were studied for shattering resistance and panicles were collected from each variety in a quadruplicate test, the samples being taken from the outside rows in 5 rod-row plots. A duplicate set of 10 sample panicles was taken at the time of maturity and a single

¹ Contribution No. 132 from the Cereal Division, Experimental Farms Service, Central Experimental Farm, Ottawa, Ontario.

² Agricultural Scientists. (Junior author on Active Service.)

set 10 days later. With 1 of the duplicate sets of 10, spikelet counts were made to determine the actual loss in field shattering up to full maturity. Similar counts were made on the panicles collected 10 days after maturity. The duplicate set of 10 panicles collected at maturity was subjected to machine shaking, the extent of agitation being 215 shakes a minute over a distance of $7\frac{1}{2}$ inches. In the same year, the same set of 8 varieties was grown in a special replicated shattering test at the Experimental Farm, Indian Head, Sask. The data obtained from this test were based on the number of shattered spikelets per panicle per row. One count was made at maturity and a second, 5 days later following an extremely high wind.

In 1942 this work was repeated at Ottawa with 12 varieties. Panicles were collected three times at intervals of 10 days, the first being taken at maturity. Duplicate samples were taken on each of the three dates for machine shaking. Shattering data were obtained as noted in the 1941 tests at Ottawa.

TABLE 1.—PERCENTAGE OF FIELD AND MACHINE SHATTERING IN EIGHT OAT VARIETIES AT OTTAWA IN 1941

Variety	1st cutting		2nd cutting*
	Field	Machine	Field
Dasix	0.9	9.6	2.8
Vanguard	5.4	14.0	7.0
Onward	2.7	7.5	19.9
Bambu	1.3	22.7	23.9
Lasalle	4.4	17.9	21.5
Len. 51-2	3.4	28.3	28.8
Banville	6.7	32.7	29.5
Ardri	4.9	19.9	61.3
Sig. difference	4.3	12.0	23.7

* No samples taken for machine shaking in 2nd cutting.

The varieties included in this test were chosen as a result of preliminary field observation and were expected to show as wide a range of shatterability as possible within the limits of the material available and without using varieties from wild species. The varieties Onward, Bambu, and Ardri are introductions from foreign sources. Len. 51-2 is a sister selection of Vanguard, and Banville is a selection of the Tartar King type. The other three varieties are grown commercially in Canada.

The variance analysis, when applied to the 1941 data at Ottawa shows a significant difference in percentage shattering between varieties in each of the three treatments. The data also show that machine shaking can be used as a means of determining differences between varieties in shatterability.

TABLE 2.—PERCENTAGE OF FIELD SHATTERING IN EIGHT OAT VARIETIES AT INDIAN HEAD, SASK., 1941

Variety	Percentage panicles showing shattering	
	Taken at maturity	Taken 5 days after maturity following heavy Wind
Dasix	10.6	23.5
Onward	18.7	7.1
Vanguard	20.7	60.8
Bambu	21.3	36.4
Lasalle	21.5	33.3
Len. 51-2	25.1	52.0
Banville	26.8	34.6
Ardri	33.9	44.4

The data from the Indian Head test in Table 2 were not taken on the basis of percentage of shattered spikelets, but rather on the number of panicles showing shattered spikelets. The Indian Head data are therefore not directly comparable with those from the Ottawa tests, but indicate in a general way that certain varieties are more resistant to shattering than others.

TABLE 3.—PERCENTAGE OF FIELD AND MACHINE SHATTERING IN TWELVE OAT VARIETIES AT OTTAWA IN 1942

Variety	1st cutting		2nd cutting		3rd cutting		Average for 3 cuttings	
	Field	Machine	Field	Machine	Field	Machine	Field	Machine
Ajax	0.1	0.7	0.9	3.7	3.8	16.5	1.6	6.9
Dasix	0.9	1.1	1.7	11.4	2.2	13.3	1.6	8.6
Erban	0.2	0.8	0.7	4.9	5.6	13.5	2.1	6.4
Ripon	0.7	1.7	0.9	13.1	4.9	19.6	2.1	11.4
Vanguard	0.8	3.3	1.3	14.7	6.9	29.4	3.0	15.8
Victory	1.4	2.6	1.1	14.3	7.3	22.6	3.2	13.2
Beaver	1.8	8.4	2.9	12.3	7.1	28.5	3.9	16.4
Roxton	0.1	1.8	0.4	9.9	12.4	10.5	4.3	7.4
Gopher	0.1	2.0	1.2	8.1	12.1	15.5	4.4	8.5
Ardri	0.8	2.6	1.6	16.3	17.5	28.0	6.6	15.6
Banville	0.5	6.3	6.4	30.8	13.6	40.9	6.8	26.0
Mabel	2.9	4.1	6.7	16.8	12.9	38.7	7.5	19.8
Sig. difference	1.4	2.4	2.7	6.0	None	7.2		

The data on the 1942 Ottawa Test, as shown in Table 3, further indicate a difference between varieties in shatterability. In this test a wider range of varieties was used and with the exception of the data obtained from the field shattering in the 3rd cutting, the analysis of variance shows a significant difference between varieties. The 1942 data also show that machine shaking as a means of creating artificial shattering can be used satisfactorily in studying differences between varieties.

DISCUSSION

The data presented in this paper appear to establish the fact that varieties of oats differ in shattering tendencies. Both in 1941 and 1942 the variety Dasix has shown high resistance to shattering, while from the 1942 data it would seem that Ajax could also be put into the resistant class. Among the varieties showing the tendency to shatter easily in both years are Banville and Ardri, while in 1942, Mabel also shows high susceptibility.

There is no indication from the data presented that shattering in oats is associated with early maturity or panicle type, except in the case of true cluster type varieties, e.g. Banville. While there is a tendency for some of the commonly grown varieties to produce more upright panicle branches than others and thus give the appearance of semi-cluster panicles, the above data do not show that this characteristic is related to shattering. Ajax, for example, might be classed as having more of a cluster type panicle than Dasix, and yet these two varieties are in the same class as regards shattering tendencies.

With regard to the relation of time of cutting to shattering tendency, it is obvious that the longer a mature crop stands in the field, the greater will it shatter both from handling and from adverse weather conditions. The 1942 data show that at the third cutting or 20 days after maturity, Ardri had shattered 17% under natural field conditions. In 1941, the same variety had shattered 61% at the second cutting or 10 days after maturity.

ATTACHMENT OF SPIKELET

According to the work of Priebis, referred to earlier in this paper, the basal attachment of the spikelet is an important character in determining the resistance or susceptibility to shattering in oats. In endeavouring to apply the findings of this author to the varieties that have been used in the data under discussion, critical studies were made by the junior author on the size and angle of the spikelet base in the case of six varieties. The varieties Mabel and Banville were studied as representing extreme shattering susceptibility, Victory and Gopher were chosen as being somewhat intermediate and Ajax and Dasix as being partially resistant.

In the case of varieties susceptible to shattering, the spikelet base approaches a 45° angle as indicated in the variety Mabel (Figure 1). This sharp angle of attachment resembles that of wild oats. On the other hand with varieties that resist shattering, the angle of spikelet attachment is much less acute and in some cases approaches a right angle. The latter is illustrated in the variety Ajax (Figure 1).

Other factors that appear to be associated with shattering are the actual area of basal attachment of the spikelet and the thickness of the sclerenchyma tissue surrounding the spikelet base. In the material studied, the amount of variation in size of base and thickness of sclerenchyma tissue was found to be considerable, but nevertheless, the indications were that these two characteristics were definitely related to the ability of the spikelet to resist shattering under adverse weather conditions. More work needs to be done on this phase of the problem.



MABEL



BANVILLE



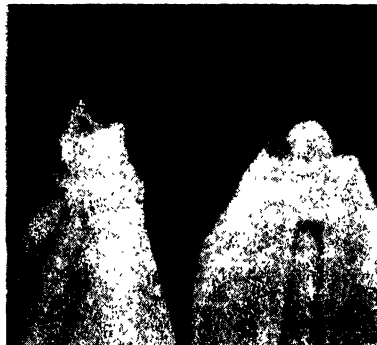
VICTORY



GOPHER



AJAX



DASIX

FIGURE 1. Size and angle of spikelet base.

SUMMARY

1. Varietal differences in resistance to shattering in oats have been established in the case of Canadian varieties.
2. Machine shaking of panicles can be used to give an index of varietal resistance to shattering.
3. The greater the angle of spikelet attachment to the peduncle, the greater the tendency to shatter.
4. It is probable that the greater the total area of the spikelet base and the thicker the sclerenchyma tissue at the attachment point, the greater the resistance to shattering.

ACKNOWLEDGMENTS

Thanks are due to Mr. J. D. Davidson, Assistant Superintendent, Experimental Farm, Indian Head, Sask., for carrying on a special shattering test in 1941 and in accumulating considerable data in connection with this problem. The authors are also grateful to Mr. P. R. Cowan, of this Division, for his assistance with the photographic work.

A PRELIMINARY REPORT ON THE CLIMATOLOGY OF THE WHEAT STEM SAWFLY (*CEPHUS CINCTUS* NORT.) ON THE CANADIAN PRAIRIES¹

H. L. SEAMANS²

Dominion Entomological Laboratory, Lethbridge, Alberta

[Received for publication February 13, 1945]

The wheat stem sawfly (*Cephus cinctus* Nort.) was first reared by Albert Kaebels in 1890 (1) from larvae mining in the stems of native grasses near Alameda, California. The adults were described the next year as *Cephus occidentalis* by Riley and Marlatt who made the suggestion that, "The economic importance of this species arises from the fact that it may be expected at any time to abandon its natural food-plant in favour of the small grains, on which it can doubtless successfully develop." In 1895, Dr. Fletcher, then Dominion Entomologist, collected specimens at Indian Head, Saskatchewan, and reported that wheat stems containing *Cephus* larvae had been sent to him from Souris, Manitoba. Since that time the insect has spread from the southwestern corner of Manitoba, across Saskatchewan and into Alberta. This spread appears to have been very gradual and has followed a definite northwesterly direction.

The prophetic statement of Messrs. Riley and Marlatt has indeed come true not only as regards sections of the United States but also as regards our Canadian prairies. The present area of infestation in Canada has suffered severe losses to wheat during the last thirty years.

The study of the wheat stem sawfly has indicated that reported crop losses are not always due to an unusual increase in numbers of the insect. With comparatively few of the insects present some fields of wheat may show a severe loss while the majority are free of infestation. On the other hand, an enormous outbreak over a widespread area may result in a small and unnoticed loss to every field of grain and a report of little or no damage may be issued for the season.

In order to study the effect of weather on the wheat stem sawfly it is first necessary to make sure that reports of outbreaks actually denote an increase in the numbers of sawflies. Such reports are not plentiful and the data on which this paper is based include only such definite information.

LIFE HISTORY

The life history of the wheat stem sawfly has been published many times and need only be briefly reviewed here. The adults begin to emerge about the middle of June and usually have all disappeared by the second week in July.

Oviposition in suitable grass or grain stems is general during this time and the eggs hatch in about 8 days. The larvae spend the summer mining up and down the stems. When the plants begin to mature the larvae move to the lower end of the stems, girdle them from the inside about an

¹ Contribution No. 2341, Division of Entomology, Science Service, Department of Agriculture, Ottawa, Canada. Presented at the World's Grain Exhibition and Conference, Regina, Saskatchewan, 1933.

² Officer-in-charge.

inch above the soil surface and spin a silken cocoon about the full length of the remaining stub. The winter is spent in the cocoons below the surface. When the soil temperature rises in the spring, the larvae become active and move freely up and down the stubs.

Pupation takes place in the cocoons during the latter part of May and early June. The pupal period lasts from 10 to 21 days depending on the temperature and moisture content of the soil. A wet cold period may delay emergence several days while a period of high temperature may hasten it.

HABITS AND REACTIONS

The emergence of adults coincides with certain events in the development of native grasses. When *Agropyron smithii* is beginning to head out, the first adult sawflies appear. At this time the majority of the *Agropyron* stems are sufficiently developed so that some portion of the stem is hollow and suitable for oviposition. Within a few hours after emerging, the female sawflies seek out such stems and begin laying eggs in the hollow portion.

Adult activity usually takes place when the sun is shining and the temperature is above 63° F. Activity ceases instantly when the sun is obscured behind a cloud or when a heavy wind is blowing. When not active the adults rest, usually head downwards, on the stems or leaves. Because of their position when at rest, a heavy rain will invariably force water under the wings and subsequent activity is delayed until they have dried the wings. A driving rain or hail undoubtedly destroys some of the adults and a prolonged wet period seems to have some effect in reducing their numbers.

The female makes a careful examination of a stem before ovipositing in it. If there is not sufficient hollow stem she moves to another until a suitable one is found. This results in the majority of eggs being laid in the strongest and best developed stems available. When the grass or grain development is poor and uneven these well developed stems will receive most of the eggs. In this connection Ainslee (1) has stated that in the spring of 1917 when weather conditions in North Dakota were such that the growth of grasses and grains was greatly hindered, odd stems of *Bromus* were found to be filled with eggs and stems of spring wheat that had barely begun to joint contained 3 or 4 eggs each. This has been found to be true many times in the investigations carried on in Manitoba and Alberta, such stems being the best available locations for oviposition.

Most publications on the wheat stem sawfly refer to the fact that the adults are weak fliers and do not travel any greater distance than is necessary in searching for suitable stems for oviposition. Since the flight activities are usually confined to the lower air levels and cease abruptly when any wind is present, the migration of the species is very slow. Thus it is that in an infested area local infestation will increase rapidly in favourable seasons while the spread to new areas is more liable to be a slow process and largely governed by the distance the adults must fly to find an abundance of stems suitable for oviposition.

When the eggs begin to hatch, the initial food of the first larvae appears to be the other eggs in the same internode followed by the eggs and larvae in the rest of the stem. The dissection of the infested stems early in the

season usually reveals the presence of 1 larva and the remains of several eggs and even other larvae, indicating that but 1 egg per stem can be expected to develop to a mature insect.

As the larvae develop they feed up and down the inside of the stems. This feeding destroys some of the food passages of the plant and at times a stem is so completely girdled that the head dies. When the plant is growing very rapidly and developing a rank growth, this feeding liberates sap into the interior of the stem which is detrimental to the sawfly larva. If sufficient sap escapes the larva is apparently drowned, but with small amounts it may possibly be a factor in promoting bacterial or fungus diseases. The determination of the presence of disease is very difficult as the finding of a dead larva covered with fungus may only indicate a saprophytic growth on a drowned larva.

EFFECT OF WEATHER ON THE DEVELOPMENT AND SURVIVAL OF THE SAWFLY

There are apparently few periods in the life history of the sawfly where weather has a direct effect on the insect. Cold wet weather in May, undoubtedly retards pupation and emergence. Observations and laboratory experiments have shown that some pupae are killed under such conditions. In contrast to this, many larvae and pupae were killed in exposed stubble by the excessively dry and hot May of 1928. These observations coupled with laboratory experiments indicate that normal pupation and emergence requires some moisture and a favourable temperature, but that freezing or a dry soil surface temperature of over 100° F. may be fatal to larvae and pupae in exposed stubble.

When the adults have emerged their activities are confined to calm periods of bright sunshine with the temperature between 64° and 90° F. A cold, rainy June with considerable wind and cloudy weather reduces the adult activity and undoubtedly kills many of them. Sweepings made after a rain do not yield as many adult sawflies as did those made previously, even though apparently normal activity has been resumed at the time the sweepings are made.

Criddle (4) suggests that dry weather may indirectly affect the development of the sawfly because it retards the development of the flowering stems. Severe drought conditions such as were experienced in southern Manitoba in 1914, caused a premature ripening of the wheat which killed a number of the larvae and seriously stunted many more. Later Criddle (3) reports that the sawfly increases in the drier areas of Manitoba in the drier years but it almost disappeared in the wet years. These statements appear to be contradictory but a dry season which may be favourable for sawfly increase, may produce some crops which are a complete failure because of the poor cultural practices that are used. During the season of 1929 there was a striking example of this in the Drumheller district of Alberta. An area of stubbled-in crop made an early start but was severely burned in July and headed out when 8 inches high. Adjoining it was a crop grown on land that was summer-fallowed the previous season. This crop suffered very little. The sawflies matured and cut the stems in both crops but those in the burned area were apparently smaller. In addition, only 40.3% of the larvae cut the stems in the poor crop while 72.8% cut

the stems in the good crop. These figures indicate that the dry conditions as they affect the host plant are an important indirect factor in the development of sawfly larvae.

A very wet season which produces a rapid and rank growth in wheat appears to be decidedly unfavourable for sawfly larval development. Many larvae are found in the stems apparently drowned in the sap. During the season of 1928 in the Drumheller section of Alberta the mortality from this cause varied from 30% to 50%. Stubbled-in crops which made a poorer growth than those grown on summer-fallowed land showed a generally lower percentage of drowned larvae but still within the limits as stated. This variation under the different methods of cropping is caused by the extra moisture supply which is available for the crop grown on summer-fallowed land and which is responsible for a ranker growth than would be found in the crops grown on stubble of the previous year. Thus the rank growth of a wet season producing plants with a greater sap flow may not only retard the development of the sawfly larvae but may even destroy them.

Criddle (4) states that, "The ideal conditions for development would be a moist spring, a dry, sunny June, and sufficient moisture during July to enable the full development of grasses or grains." In correspondence with Criddle regarding Manitoba conditions and King³ concerning Saskatchewan, they both agree that a wet July is decidedly detrimental to the development of sawfly larvae. This condition appears to hold in a number of cases and a wet July usually indicates a decreased infestation the next year. There are a few striking examples where the reverse is true and the question of July rainfall will therefore be more thoroughly discussed later.

There are other factors which must be considered before an accurate statement can be made concerning the most favourable weather conditions for sawfly increase. Observations have shown that excessive drought conditions are as detrimental as excessive moisture. These terms are relative and in many cases will only apply to individual fields. For the most part only moisture recognized as precipitation has been considered. Future work must consider the soil moisture and the moisture storing capacity of the soil.

The loss of moisture due to drainage and evaporation in a sandy soil such as that at Treesbank, Manitoba is greater than that of the soil of Saskatoon, Saskatchewan which contains more clay. On the other hand, the heavy "gumbo" (clay-loam) soil of the Drumheller district in Alberta absorbs moisture readily and permits of very little loss by drainage or evaporation. Thus any statement concerning rainfall and plant development must consider the type of soil. This accounts for a particular season causing a crop failure in one area when a duplicate of that season might produce a good crop in a district with a different type of soil. The reaction of wind and temperature on the different soils must be considered as these affect the moisture content and the host plant development. Some soils will bake with a solid surface crust when a period of heavy rainfall is followed by high temperature, and this crust practically prevents surface

³ K. M. King, Officer-in-charge, Dominion Entomological Laboratory, Saskatoon, Sask.

evaporation either with high temperature or heavy winds. Other soils form a loose crust which retards evaporation but is readily broken up by wind and the moist soil below is exposed.

There is one point where weather is an indirect factor in controlling the actual decrease or increase of the sawfly. This concerns the development of grasses and grains in the spring. Field studies correlating the emergence of adult sawflies with grass development have shown that when the first heads appear on native *Agropyron* the sawflies begin to emerge. The height of emergence and the maximum oviposition coincides with the heading out of 25% of the *Agropyron* flowering stems. Ainslee (1) states that the females never choose stems for oviposition that have put forth a head. This certainly is not true in Alberta as these stems appear to be much preferred, apparently because of the extent of the hollow stem that is present. If there are only a few such stems, they will receive the bulk of the eggs laid. It is rather interesting to note that these stems may receive eggs late in the oviposition period even though a well developed larva is present in each one. The result of such a condition is that many of the eggs laid are destroyed by the sawfly larvae. During the season of 1927 when seeded grain was slow in developing, a large number of stems were dissected at the end of the second week of the oviposition period. Not all the stems contained eggs, but those that did averaged 7 eggs per stem. This meant that the uneven development of the host plant had been responsible for the destruction of 6 out of 7 potential larvae by cannibalism due to egg concentration in available host plants. Had the grass and grain developed evenly the eggs would have been distributed among a larger number of stems and the resulting destruction of eggs would have been relatively less.

WEATHER CONDITIONS FAVOURABLE FOR SAWFLY INCREASE

The ideal conditions for sawfly increase can be summed up from laboratory and field investigations as follows:

- (1) A fairly wet fall to provide a moisture reserve for the starting of grass and grain in the spring.
- (2) Either a mild winter or one with sufficient snow to protect the larvae and host plants from too severe conditions and enable them to make a strong growth in the spring.
- (3) A warm moist May without temperature extremes, which will develop an even stand of host plants and allow maximum emergence.
- (4) A sunny June with sufficient rainfall to produce rapid plant growth and not enough to unduly restrict adult activity.
- (5) A July with sufficient moisture and high enough temperature to produce a steady plant growth without the plant becoming rank—to insure even and maximum larval development and no larval destruction through sap drowning.

These conditions are somewhat vague as they do not include definite values. To reduce these factors to a workable basis it is necessary first to determine what shall constitute a definite year of weather influence. The weather apparently affects the sawfly more through its influence on the

host plants than in a direct way. In general the agronomists consider a crop year over the prairie region as starting with the first of August. This is based on the fact that moisture received after that date is of more value to the crop of the next season than it is to the crop about to be harvested. Starting the year at August also brings all the factors which directly affect the sawfly into the same year with the conditions which indirectly affect it.

Having accepted this basis, the weather records for the Canadian prairies were studied in connection with known increases of sawfly population irrespective of the amount of actual damage done. Only authentic records of known increase have been considered, and while these are not plentiful the results should be more accurate than if uncertain data were used. For the purpose of this paper a "season" of sawfly increase is a particular year at a particular point. The fact that a marked sawfly increase occurred in the same year at two different points does not mean that it is the same climatic "season" since the amount of rainfall, the mean temperature and soil conditions vary to such an extent that the actual conditions may be as totally different as if they occurred in two different years.

Ten seasons of marked sawfly increase were chosen from reports of localities scattered throughout the infested areas as follows:

Treesbank, Manitoba, 1907, 1914, 1918, 1921 and 1922.

Saskatoon, Saskatchewan, 1923.

Swift Current, Saskatchewan, 1926.

Three Hills, Alberta, 1926.

Hanna, Alberta, 1926.

Medicine Hat, Alberta, 1927.

There are other years at these and other points where increase in sawflies is known to have occurred but these ten represent ideal outbreaks. The results and conclusions presuppose that the year ending July 31 which preceded each of these outbreaks approached optimum conditions for the sawfly. The precipitation and temperature records for these preceding years were tabulated as shown in Table 1.

Each of these ten years it is presumed contains the essential factors favourable for the development of the sawfly in that locality and the average of these ten years should represent an index of optimum conditions. A study of this average in correlation with the ideal conditions for sawfly increase, as previously enumerated, shows the fall season to be fairly wet followed by a cold winter with an even snow distribution and a gradual approach of spring. May has sufficient moisture, with the help of the fall reserve, to produce an even growth of host plants and the temperature is high enough to hasten this growth. June does not carry excessive moisture and has a high temperature which indicates considerable sunshine to promote adult activity while July is somewhat drier and hot enough to bring the host plants to seasonable maturity.

If the individual years are compared with the average and with each other there seems to be a wide range of dissimilarity. This is evidenced in a month to month examination as well as in the total amount of rainfall for the year. Much of this can probably be fully explained after a study of the soil types and their ability to retain moisture has been made. It is rather interesting to note that the two locations which have a sandy soil,

TABLE 1.—MONTHLY MEAN TEMPERATURE AND PRECIPITATION RECORDS FOR THE 12 MONTHS' PERIOD ENDING JULY 31,
PRECEDING SEASONS OF SAWFLY ABUNDANCE

Place	Year	Tresbank												Threethills		Hanna		Medicine Hat		Saskatoon		Swift Current		Average	
		1906		1913		1917		1920		1921		1925		1925		1926		1922		1925		Temp.		Pptn.	
		Temp.	Pptn.	Temp.	Pptn.	Temp.	Pptn.	Temp.	Pptn.	Temp.	Pptn.	Temp.	Pptn.	Temp.	Pptn.	Temp.	Pptn.	Temp.	Pptn.	Temp.	Pptn.	Temp.	Pptn.	Temp.	Pptn.
	Aug.	67	1.67	62	1.10	65	1.57	67	1.29	69	3.50	58	1.27	59	2.80	66	1.47	62	.62	62	2.48	63	1.84		
	Sept.	58	2.56	51	4.26	54	1.72	55	1.69	58	2.29	51	.80	52	2.28	54	3.25	51	2.98	55	.65	54	2.25		
	Oct.	38	.70	43	.67	37	2.74	31	1.83	47	1.14	41	1.40	43	1.26	37	.29	43	.36	46	2.76	41	1.31		
	Nov.	28	.50	29	.26	26	.36	11	1.16	26	1.21	19	.35	21	.40	33	.30	16	1.52	23	.98	23	.70		
	Dec.	13	.52	12	1.09	1	1.23	3	.56	9	.71	2	.32	2	1.50	27	.53	7	.45	5	.93	8	.78		
	Jan.	7	1.12	6	1.08	7	1.79	5	.98	7	.76	5	.20	6	.40	24	.62	0	.50	10	.87	5	.83		
	Feb.	3	.12	1	.90	5	.98	8	.89	11	1.46	7	.58	8	.30	28	.25	9	.53	16	.22	8	.62		
	Mar.	17	.67	10	.97	21	.37	17	.71	17	1.12	20	.47	19	.20	37	.27	16	.85	24	.91	20	.65		
	April	47	.92	47	.30	34	1.37	28	.38	36	1.65	42	1.38	42	3.01	48	.32	38	.37	45	2.38	41	1.21		
	May	49	3.00	51	1.09	50	.10	54	.68	53	1.77	51	1.77	52	.64	59	1.65	54	2.09	54	.85	53	1.36		
	June	65	2.53	66	2.64	59	1.91	62	3.68	68	2.95	58	1.74	61	1.98	64	1.14	62	1.28	60	1.56	62	2.14		
	July	70	1.21	64	2.26	70	1.27	66	2.46	72	.89	62	1.99	63	3.63	63	2.47	64	.79	67	1.29	66	1.86		
	Total pptn.		15.52		16.62		15.41		16.22		19.45		12.27		18.50		12.56		11.98		13.88		15.55		

i.e. Treesbank and Hanna, also had the highest yearly precipitation preceding outbreaks, while that of the areas of heavier soil was much lower. In seven of the ten seasons the July rainfall was less than that of June, but at Hanna and Medicine Hat it was so much higher than June that some explanation appears necessary.

The fall moisture was evidently sufficient to create an excellent reserve in the soil since there were over 6 inches of rain before the first of November at Hanna and over 5 at Medicine Hat. The coldest part of the winter was accompanied by fairly heavy snow at Hanna while Medicine Hat had a milder winter. The host plants at both places made a good start in May on the reserve moisture of the fall combined with that of April. June was apparently ideal from the standpoint of adult activity and the heavier precipitation of July was necessary to produce strong plant growth and prevent drought conditions resulting from the smaller amount of May and June precipitation. This indicates that the accumulated moisture in the soil during the three months' growing period was only sufficient to produce a normal and healthy plant growth and that the apparently excessive moisture of July was not actually sufficient to produce the rank stem so detrimental to sawfly larvae as would have been the case had May and June been wetter. Thus the precipitation and temperature of any one month cannot be considered as directly or indirectly influencing sawfly increase while conditions prevailing in the previous months are disregarded.

WEATHER CONDITIONS UNFAVOURABLE FOR SAWFLY INCREASE

There are apparently two sets of conditions which are unfavourable for sawfly development. One of these is a "wet year" and the other is extreme drought conditions. These conditions not only affect the yearly fluctuations throughout the present area of infestation but are apparently limiting climatic factors in the spread of the insect into new territory. Since a "wet year" is the most common controlling factor it will be discussed first.

Ten seasons showing a marked decrease in sawfly abundance were taken from reports of the same localities as used in the discussion on sawfly increase. These seasons were picked following a heavy outbreak as near as possible and are as follows:

Treesbank, Manitoba, 1923, 1924, 1925.

Saskatoon, Saskatchewan, 1924.

Swift Current, Saskatchewan, 1927, 1928.

Three Hills, Alberta, 1927, 1928.

Hanna, Alberta, 1927.

Medicine Hat, Alberta, 1928.

The temperature and precipitation records of these seasons are shown in Table 2.

As the records of years preceding increase contained certain conditions favourable to the sawfly development, so each of these years and the average should contain conditions which are unfavourable. The average of these ten years shows less moisture in the fall and winter, which means a shortage

TABLE 2.—MONTHLY MEAN TEMPERATURE AND TOTAL PRECIPITATION RECORDS FOR "WET YEARS" ENDING JULY 31,
PRECEDING SEASONS OF KNOWN SAWFLY DECREASE

Place	Year	Treesbank						Saskatoon		Swift Current				Three Hills				Hanna		Medicine Hat		Average			
		1922		1923		1924		1923		1926		1927		1926		1927		1926		1927		Temp.		Pptn.	
		Temp.	Pptn.	Temp.	Pptn.	Temp.	Pptn.	Temp.	Pptn.	Temp.	Pptn.	Temp.	Pptn.	Temp.	Pptn.	Temp.	Pptn.	Temp.	Pptn.	Temp.	Pptn.	Temp.	Pptn.	Temp.	Pptn.
Aug.	66	2.65	2.97	61	1.79	65	3.87	64	1.79	69	2.49	58	.98	64	1.88	59	.92	73	.56	65	1.99				
Sept.	55	5.14	3.05	58	.88	56	.77	53	2.68	45	1.09	48	2.73	41	3.16	49	.99	48	1.50	51	2.20				
Oct.	45	.55	.34	43	1.09	40	.86	31	.90	42	.62	31	.43	41	.16	31	.32	48	.02	39	.53				
Nov.	17	.85	.72	34	1.06	26	.13	29	.15	22	.77	26	.23	19	1.25	27	.45	28	.95	26	.64				
Dec.	12	.30	1	1.91	.50	16	.85	21	.23	11	.40	23	.60	7	.30	21	1.30	16	2.15	12	.85				
Jan.	1	.70	1	1.38	4	1.09	1	37	19	1.10	14	.48	19	.42	6	.18	18	.90	16	10	.68				
Feb.	2	.97	1	1.04	12	.68	2	.62	21	.45	12	1.10	18	1.04	6	.55	18	1.00	16	4.9	11	.79			
Mar.	24	1.29	7	1.36	.58	11	.80	30	.31	27	1.42	32	.51	21	.93	26	.50	33	1.10	23	.88				
April	42	1.04	33	1.68	5.10	36	.69	44	.13	40	1.16	42	.08	37	.75	40	.36	42	1.60	42	1.26				
May	56	2.81	52	1.60	.46	.35	52	1.65	56	2.65	47	6.58	51	.62	45	2.25	48	1.66	50	5.30	50	2.55			
June	65	2.28	66	3.23	58	1.93	62	5.11	58	2.33	61	1.11	56	4.04	57	2.50	56	3.69	63	1.31	60	2.75			
July	65	3.19	70	3.63	65	4.95	66	5.37	62	3.54	65	3.47	57	4.07	61	2.54	63	3.00	68	5.43	64	3.92			
Total pptn.		19.87	22.91		20.99		21.09		16.26		20.69		15.75		16.45		15.09		20.48		19.04				

of reserve moisture for promoting spring growth, with a higher winter temperature indicating frequent thaws and freezes. Periods of warm weather in the winter followed by severe cold are apt to start plant activity and seriously injure the plants with the freezing that follows. This would tend to cause a more uneven development of host plants early in the season with a subsequent concentration of eggs in fewer stems. Such a concentration means a reduction in the ratio between eggs laid and larvae maturing. May and June are both fairly wet with slightly lower temperatures which would cause a reduction in the number of pupae emerging as well as the activity and number of adults surviving. July has excessive moisture following that of the two previous months and insures a rank and succulent stem in which larvae are apt to be drowned. The average yearly precipitation is higher in the unfavourable years and most of this increase occurs in the three critical months of May, June and July.

A study of the individual years shows that in most cases the fall is drier than it is in favourable years. Those years in which May rainfall and temperature are favourable for pupal development, contain either a very wet April or a very wet June and in all of them July is wetter than the average favourable conditions. While one or two of the critical summer months may be favourable or approach the favourable conditions for sawfly development and increase, the combined conditions are distinctly adverse.

The data on dry conditions producing a decrease in sawfly population the next season is very meagre. There are districts within the main area of infestation where the sawfly is seldom seen and then only in years of more than average precipitation. This fact has led to the supposition that some climatic factor is largely responsible for this condition since no other tangible barrier exists to block these areas out from the surrounding infestation. In order to arrive at a conclusion regarding the effect of a dry year on the development of the sawfly the average climate of six places where sawfly is generally present but rarely increases were studied. These are the averages shown in Table 3.

TABLE 3.—THE AVERAGE CLIMATES OF SIX LOCATIONS WITHIN THE AREA OF SAWFLY INFESTATION WHERE OUTBREAKS ONLY OCCUR FOLLOWING WET YEARS

Place	Alberta										Saskatchewan		Average	
	Bow Island		Brooks		Empress		Grassy Lake		Prospry		Govenlock			
	Temp.	Pptn.	Temp.	Pptn.	Temp.	Pptn.	Temp.	Pptn.	Temp.	Pptn.	Temp.	Pptn.	Temp.	Pptn.
Aug.	64	1.23	61	1.77	66	2.10	64	1.77	61	.98	64	1.15	63	1.48
Sept.	55	1.22	51	.80	52	.65	55	1.13	51	.78	54	1.08	53	.94
Oct.	46	.44	40	.78	46	.40	46	.60	42	.67	42	.46	44	.56
Nov.	30	.73	23	.41	30	.30	30	.35	25	.87	30	.21	28	.48
Dec.	21	.63	17	.76	14	.75	21	.56	14	.86	9	.61	17	.69
Jan.	12	.72	7	.41	7	.55	13	.54	9	1.18	1	.84	8	.66
Feb.	16	.82	9	.51	6	.36	17	.33	12	.89	11	.28	12	.53
Mar.	27	.60	23	.58	19	1.07	27	.40	14	1.31	23	.45	22	.73
April	43	.93	42	.89	43	1.37	43	.75	40	1.56	40	.85	42	1.06
May	53	.71	51	1.23	52	1.33	54	1.26	49	1.60	52	.96	52	1.18
June	61	2.36	58	1.47	62	2.50	61	1.60	58	1.74	61	1.68	60	1.90
July	66	1.22	63	1.46	62	1.28	66	1.22	62	1.67	70	1.46	65	1.38
Total pptn.		11.63		11.07		12.66		10.01		14.02		10.03		11.69

The average weather of each of these localities shows a small reserve fall moisture which is barely sufficient to start plant growth in the spring. May conditions are favourable for pupation and emergence, though the uneven plant development would cause a greater concentration of eggs in suitable host plant stems than occurs in the wet years. June is generally favourable for sawfly activity but the weather conditions of July would produce a drought condition which would be decidedly detrimental to normal development of the larvae.

SUMMARY OF WEATHER CONDITIONS

Comparing the general averages of the three sets of weather conditions as shown in Tables 1, 2 and 3, the dormant period of the sawfly from November 1 to April 30 is almost identical in each. The following is the total precipitation and the mean temperature for each set of conditions:

Dry		Favourable		Wet	
Total precipitation	Temp.	Total precipitation	Temp.	Total precipitation	Temp.
4.15 in.	21.5° F.	4.79 in.	17.5° F.	5.10 in.	21.7° F.

As there is only a difference of 4.2° F. in mean temperature and .95 inches of precipitation between the highest and lowest records, the average dormant period can hardly be considered as containing important factors governing changes in population.

A comparison of individual months during this period shows a wide variation of conditions from the average for each series of years but the monthly averages for the three conditions are very similar.

The remaining six months of the year are separated into two groups of three months each by the six months' period of dormancy. The fall group consists of August, September and October a period when the larvae are in the stubble and approaching a dormant state. The summer group consists of May, June and July, a period where pupation and emergence, adult activity, and the greatest larval activity and development occur.

The average precipitation and mean temperature for each of the fall months as shown in Tables 1, 2 and 3 is as follows:

	Dry		Favourable		Wet	
	Total precipitation	Temp.	Total precipitation	Temp.	Total precipitation	Temp.
Aug.	1.48	63	1.84	63	1.99	65
Sept.	.94	53	2.25	54	2.20	51
Oct.	.56	44	1.31	41	.53	39

August is similar in both precipitation and temperature for each set of conditions. September is similar in the favourable seasons and the wet unfavourable seasons, while in the dry unfavourable climate it is much drier. October of the two unfavourable seasons has almost an inch less moisture than the favourable seasons. It would appear that the October moisture is an important factor and yet an examination of Tables 1, 2 and 3 shows that for individual seasons the same October conditions can be found in each. The same is true of the months of August and September.

The monthly average precipitation and mean temperature for each of the summer months as shown in Tables 1, 2 and 3 is as follows:

	Dry		Favourable		Wet	
	Total precipitation	Temp.	Total precipitation	Temp.	Total precipitation	Temp.
May	1.18	52	1.36	53	2.55	50
June	1.90	60	2.14	62	2.75	60
July	1.38	65	1.86	66	3.92	64

A study of these figures shows that these months in the wet year which is unfavourable for sawfly increase have higher precipitation and slightly lower temperatures than the favourable year, the most outstanding feature being the very heavy July precipitation. The dry climate which is unfavourable for sawfly increase has less precipitation per month than the favourable year. Here again the averages indicate a possible weather correlation with sawfly fluctuation which does not occur in the individual years. For instance, July, 1925, at Hanna, Alberta (see Table 1) had 3.63 inches of precipitation and yet was followed by a heavy sawfly outbreak the next season. An examination of these tables will show years which have monthly precipitation records for each of the months equal to the averages for the different conditions.

It is apparently impossible to correlate any weather conditions of a single month with sawfly fluctuation. It is equally impossible to find a definite correlation between total yearly precipitation and sawfly fluctuation since there are years favourable for increase which have a greater total precipitation than some years which have been classed as wet that preceded a marked decrease.

A careful study of host plant development as well as sawfly activity and development indicates that cumulative moisture is a more important factor than monthly precipitation. The total precipitation for August, September, and October without high evaporating temperatures or low freezing temperatures, constitutes a reserve moisture of importance to spring growth. With the freezing of the ground in November, winter precipitation is inclined to run off instead of materially increasing the reserve. A good fall reserve means that less precipitation is needed in the spring and summer to produce a satisfactory plant growth for sawfly development, but a low fall reserve requires a heavy precipitation throughout the growing period. Such a condition produces uneven growth and usually a very rank growth. A year such as that shown in Table 1, at Hanna, Alberta, 1925, with a good fall reserve of moisture did not require a heavy summer precipitation until July. Coming at this time, after a dry May and June, it was not excessive.

To get the effect of cumulative moisture and find a correlation between weather and sawfly fluctuations, the year has been divided into four periods of three months each, starting with the first of August. The total precipitation and mean temperature for each period can be used as an index of cumulative moisture but until actual soil studies are made this will not be accurate. The average from Tables 1, 2 and 3 show the following indexes of cumulative moisture.

	Dry		Favourable		Wet	
	Precipitation	Temp.	Precipitation	Temp.	Precipitation	Temp.
Aug.-Oct.	3.08	59	5.36	52	4.71	52
Nov.-Jan.	1.83	18	2.31	12	2.18	14
Feb.-April	2.52	25	2.71	23	2.92	26
May-July	4.46	59	5.38	58	9.31	56

The areas of light infestation which are listed under Table 3 representing weather conditions too dry for sawfly increase are not as satisfactory as they would be if actual dry seasons preceding decrease would be used. Unfortunately data for drought conditions throughout the infested area are not available. The areas used have a light soil which would not hold moisture as well as the heavier soils so that a 3.08 inch fall reserve with a mean temperature for the three months of 59° F. would not leave a great reserve for starting spring growth. The summer precipitation of 4.46 inches with a mean temperature of 59° F. would be sufficient to produce a light crop of irregular development.

The column representing the wet season unfavourable for sawfly increase covers all types of soils, and in studying individual years at definite locations the soil type would have to be taken into consideration. The fall moisture of 4.71 inches represents a good reserve and the mean temperature of 52° F. could hardly be considered as causing an excessive evaporation. The summer precipitation of 9.31 inches is certain to produce an excessively rank growth, especially with a mean temperature of 56° F. which probably indicates hot wet weather in July. Even though July be inclined to dry conditions the high temperature with the excessive cumulative moisture would cause a rank plant development.

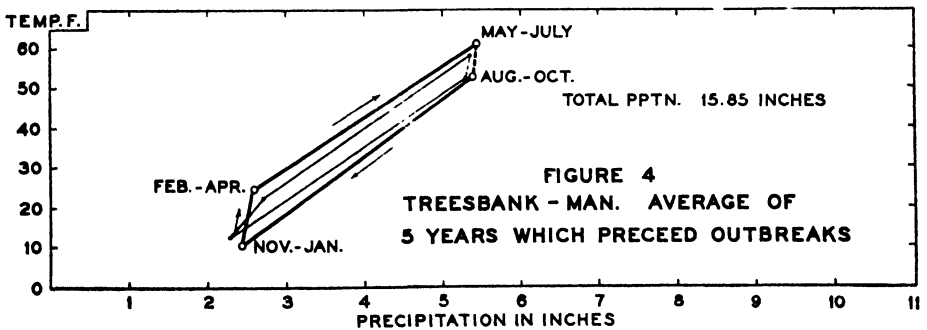
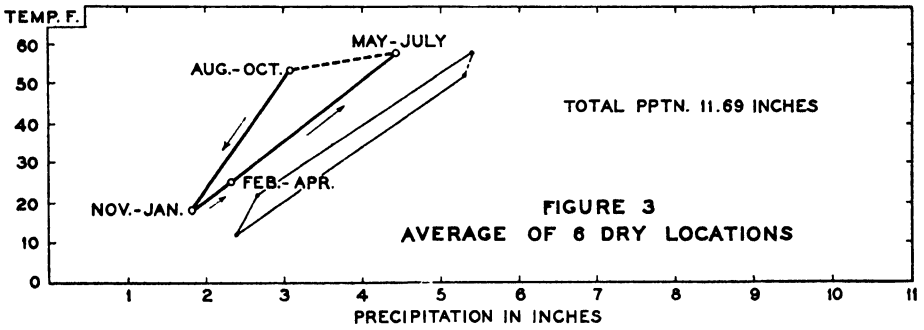
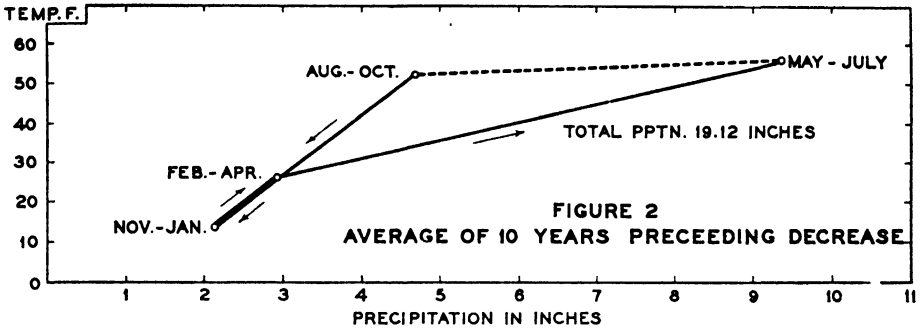
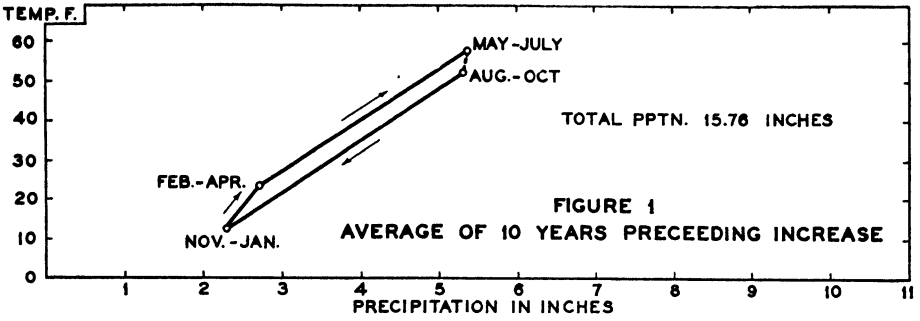
The conditions favourable for sawfly increase shown by these figures indicates a good fall reserve with medium precipitation and high temperature the following summer. The lower precipitation and higher temperature usually confined to July makes a strong stemmed host plant ready to mature early in August when the larvae are full grown, but not rank enough to drown the larvae inside the stem.

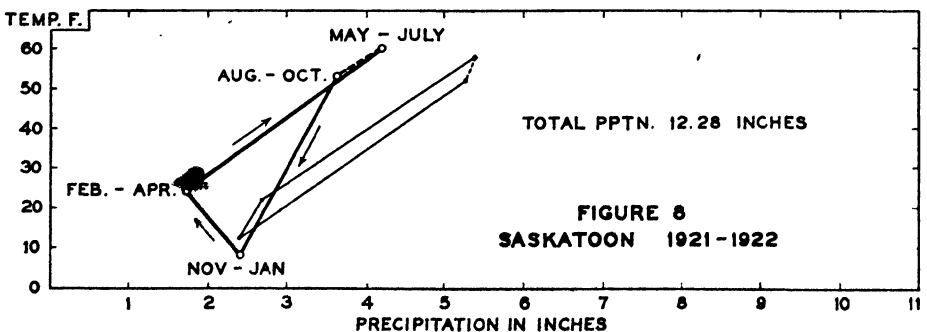
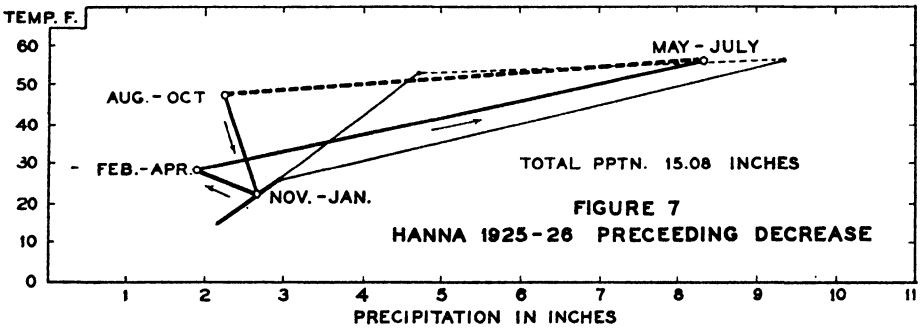
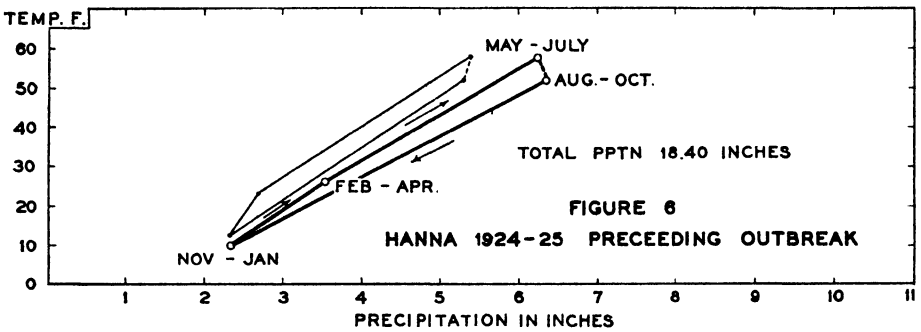
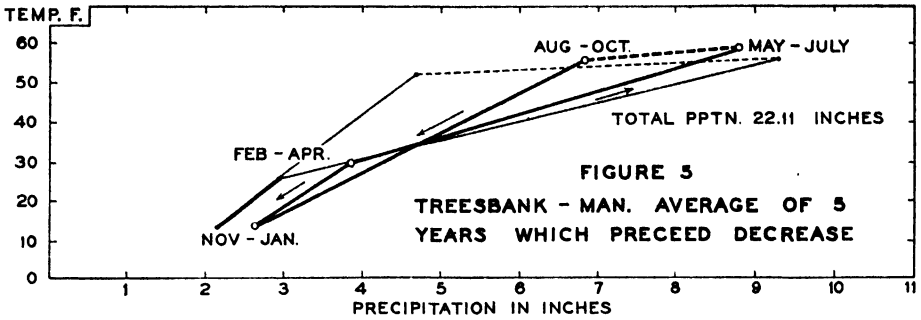
The averages as shown by the figures agree better with individual years as shown in Tables 1, 2 and 3 than do the straight monthly figures. The results can be plotted as "three months' cumulative" hythergraphs.

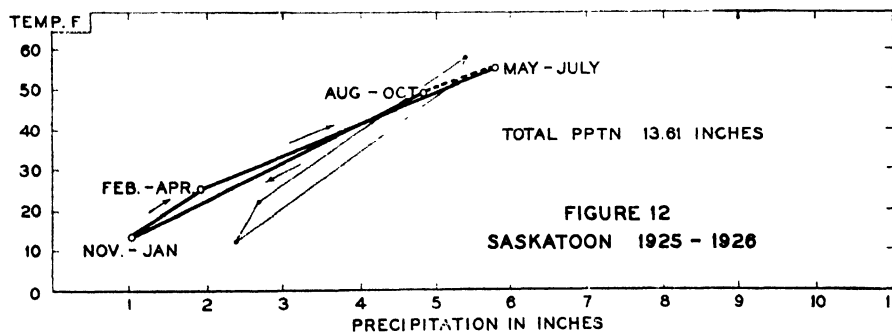
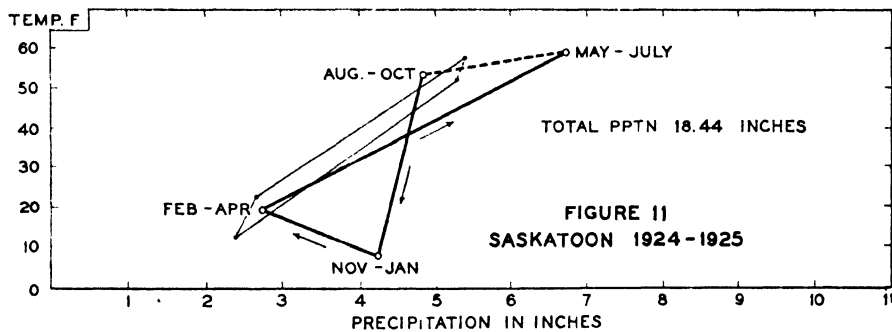
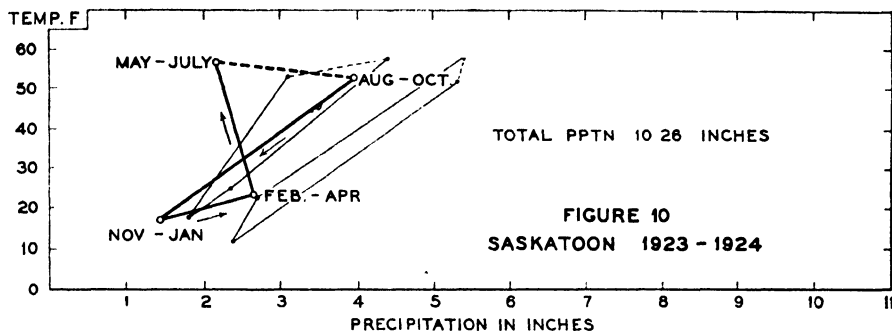
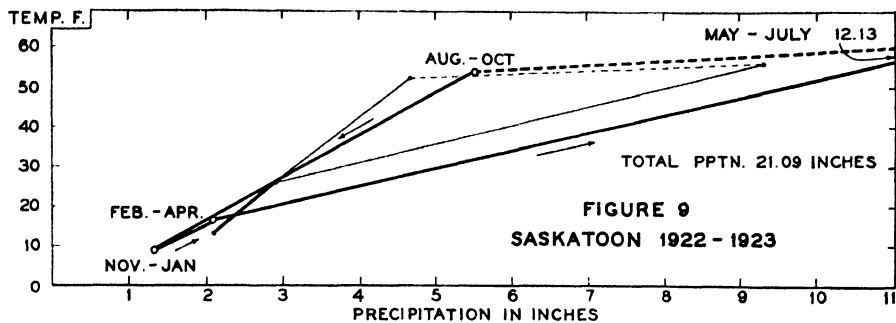
Figure 1, is a graphic representation of the cumulative index taken from the averages of Table 1. As this represents the average of ten years preceding marked sawfly increase throughout the infested area it is used as a general index of optimum conditions for the sawfly.

Figure 2, is a graphic representation of the cumulative index taken from the averages of Table 2. The years upon which this is based all preceded a marked decrease of the insect. The main differences between the two graphs are the precipitation for the August-October and May-July periods.

Figure 3, is made from the averages of Table 3 and represents the general cumulative index of the average climate of the six points studied. While this does not actually represent years which preceded sawfly decrease







because of drought conditions, it does represent conditions under which the sawfly has seldom been troublesome enough to attract attention even though it has been present for several years.

Since these hythergraphs represent average conditions, the weather of any one year can be plotted in the same manner and the result compared for a correlation with sawfly fluctuations.

Figure 4, shows a three months' cumulative hythergraph which is the average of five years preceding serious outbreaks at Treesbank, Manitoba. Figure 5, is the average of five years preceding decrease in populations at the same place. Figures 1 and 2, are shown in fine lines for comparison.

Figure 6, is the three months' cumulative hythergraph for the single year ending July 3, 1925 at Hanna, Alberta, compared with the "optimum index." While both the fall and summer periods have a slightly lower temperature and higher precipitation than the optimum index it is close enough to indicate the increase of sawfly.

Figure 7, is the graphic representation of the following year at Hanna, Alberta (ending July 31, 1926). This hythergraph is compared with Figure 2 in fine lines and here again there is a marked similarity. The dry fall period of 1925 probably was as big a factor in reducing numbers as the excessive moisture of the summer period of 1926. It is interesting to note that the total yearly precipitation represented by Figure 6 is 3.32 inches greater than that of Figure 7 but the seasonal distribution determines the difference between two years in regard to sawfly fluctuation.

K. M. King of the Dominion Entomological Laboratory at Saskatoon has made some very careful studies in regard to sawfly fluctuations in connection with his soil rotation studies. He has very kindly furnished some of his data. This has been correlated with the moisture and temperature studies for this paper. King states that in the season of 1923 sawfly was very abundant in the vicinity of Saskatoon but the excessive moisture of that season caused a very high mortality with a corresponding decrease in infestation in 1924. Another factor appeared in 1924 which would not show in the hythergraphs. This was a severe frost in May after larval activity had been resumed. King records a mortality of 15 to 20% at this time. The season of 1924 was dry and crops amounted to practically nothing. This drought condition should have caused a reduction in numbers in 1925. The next season, 1926 was one of the worst on record in Saskatchewan for sawfly infestation and King stated that a great majority of the larvae apparently entered the winter of 1926 in good condition for the season of 1927.

Figures 8 to 12 show the weather conditions during the period from the end of July 1922 to the end of July 1926, which covers the sawfly fluctuation for the seasons of 1923-27. The year ending July 31, 1922 (Figure 8) was fairly dry but with sufficient fall and summer moisture to produce a fair crop with little effect on the sawfly, even though it approaches the dry conditions as represented by Figure 3. This would produce the numbers present in the season of 1923. The year ending July 31, 1923 (Figure 9) follows closely the hythergraph of a year preceding decrease (Figure 2) except for the abnormally high summer precipitation. This could cut the population to a minimum in 1924 even if the heavy frost of late May in

1924 had not occurred. The year ending July 31, 1924 (Figure 10) was very dry though crops would get a fair start from the excess moisture of 1923. The very dry May-July period of 1924 produced drought conditions which were certainly not favourable for an increase in sawfly abundance. Thus the season of 1925 would not show any increase in population over 1924 but the year ending July 31, 1925 (Figure 11) was favourable for a marked increase in 1926. The fall precipitation with its attendant favourable temperatures was conducive to a good reserve supply of moisture and though the period of November-January was cold, the heavy snow gave ample protection if it was needed. The May-July precipitation and temperature were favourable though there was more moisture than the optimum index. Since this followed a very dry year this extra precipitation may have been necessary to promote favourable growth. The general conditions were nearer the optimum index than they were to the unfavourable and would be expected to produce a marked increase in sawfly population. The year ending July 31, 1926 (Figure 12) was favourable for increase from the standpoint of precipitation. The lower temperature may have affected the development of the sawfly but this is not very probable since the mean for the summer months is only two degrees below the optimum index.

CLIMATE AND THE DISTRIBUTION OF THE WHEAT STEM SAWFLY

The sawfly has apparently spread very gradually across the Canadian prairies. The map (Figure 13) shows the present area of economic distribution as well as that part of it where the insect is of greatest economic importance. In this latter area the sawfly is always present and outbreaks are frequent. Outside of this but within the area of economic distribution losses have occurred but outbreaks are seldom as frequent or severe.

There are localities within both areas where the insect is known to be very scarce, and a thorough survey would undoubtedly show more of these. As these localities are surrounded by constant infestation it seems probable that the local climate may be a factor preventing the sawfly becoming well established. A considerable area northwest and west of Medicine Hat, Alberta, extending from Youngstown through Brooks (represented by double line on the map) has had little or no trouble. The insect is present in that portion of the area north of the river and on rare occasions has caused small losses. A study of the precipitation map of the Dominion Meteorological Service shows the precipitation of this area to be between 11 and 13 inches annually. The general area of infestation follows roughly the districts having between 13 and 17 inches of precipitation in the heavier soil area and 15 to 19 inches where the soil is sandy. This particular dry area is a light soil district and with the attendant low precipitation it may act as a barrier to the southwestern advance of the sawfly. Except for one or two places the insect has not crossed the Bow River in Alberta. In one locality south of Gleichen the sawfly occurs for six or seven miles south of the river. This is an area of medium light soil with an average yearly precipitation of 15 or more inches. After the Bow River joins the South Saskatchewan the insect has crossed in the vicinity of Medicine Hat and traces have been found to the Montana border as indicated by the dotted area on the map. Essentially a dry section of Alberta this particular strip

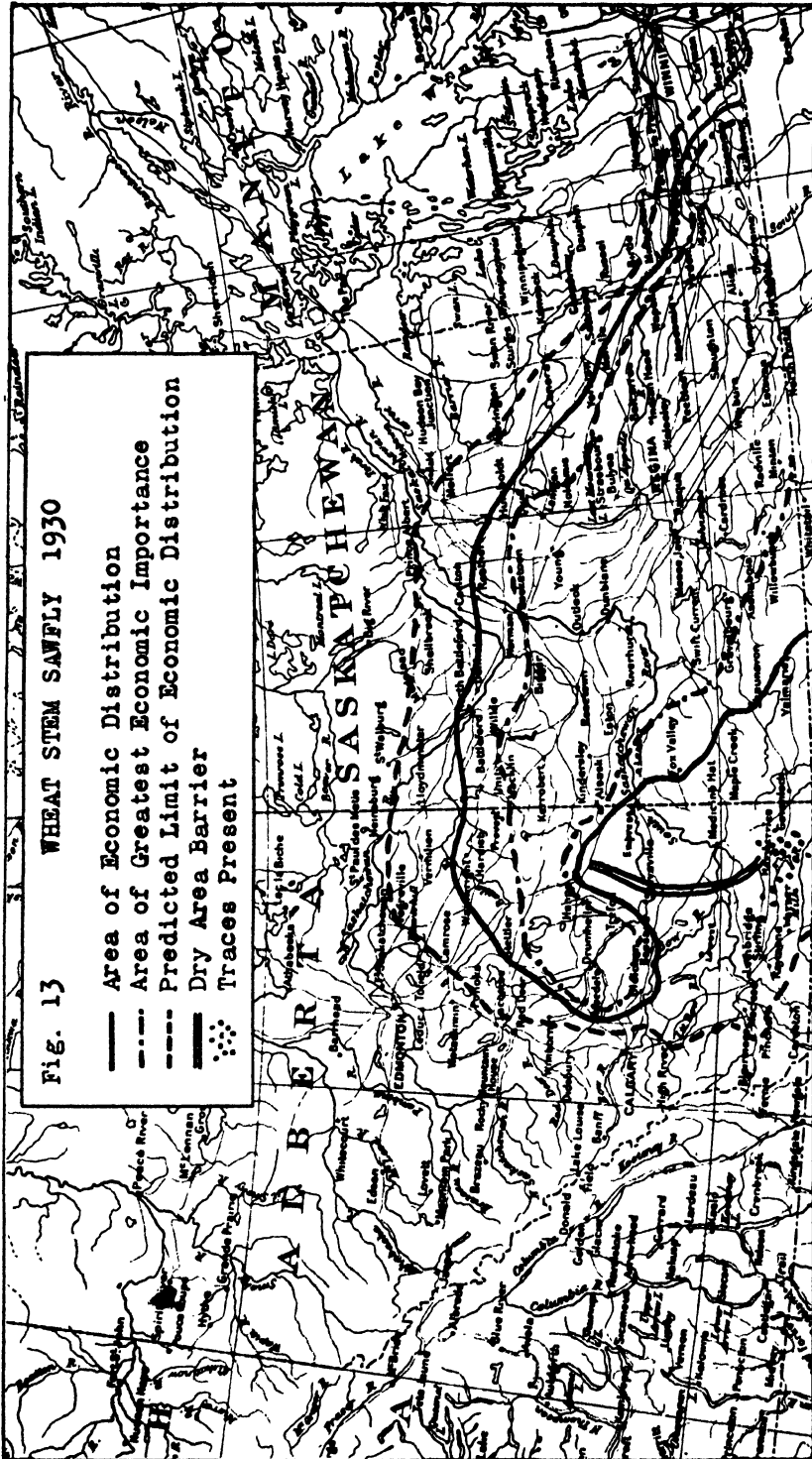
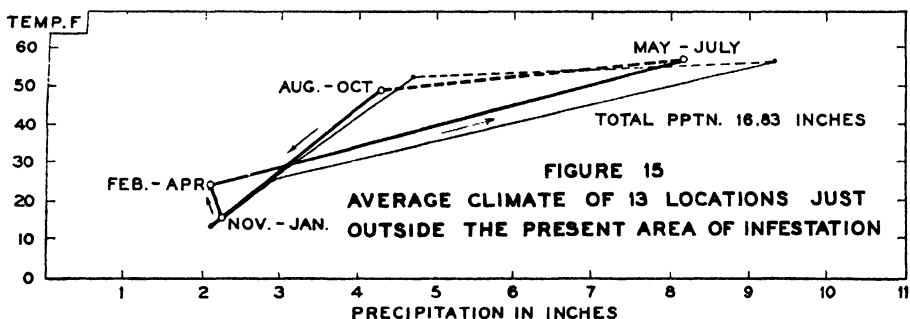
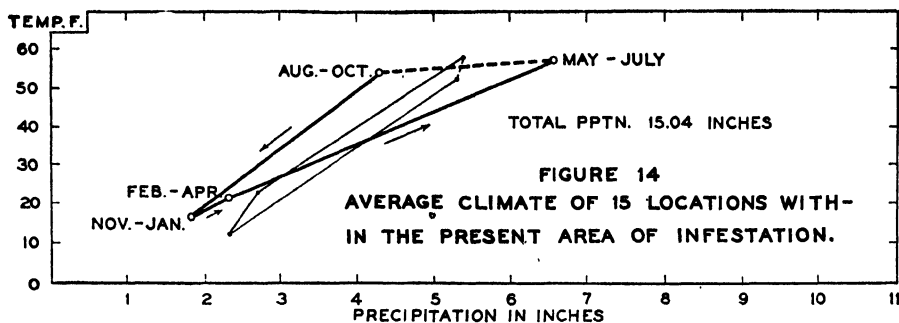


FIGURE 13.

is affected by the Cypress Hills and the precipitation here is about 15 inches. There is no doubt that rivers the size of the Bow and South Saskatchewan would act as partial barriers to such a weak-flying insect as the wheat stem sawfly, but its westward migration from the present south-eastern infestation in Alberta is apparently much slower because of the dry strip represented by the double line. The eastern migration from this same light infestation may be partially stopped by the excessive precipitation of the Cypress Hills and the dry area south of them at Govenlock, Saskatchewan.

In order to find a correlation between the weather conditions affecting yearly fluctuations and the climate affecting distribution of the sawfly, hythergraphs were made for comparison. The fifteen locations within the area of heaviest infestation which had the longest series of weather records were selected. These records were averaged and plotted as a three months' cumulative hythergraph. Figure 14 shows the result compared with the optimum index as shown in Figure 1. The period of May-July has slightly over 1 inch more precipitation than the optimum index while the fall period has 1 inch less. A year such as is represented in Figure 14 when occurring in a heavy soil area might be too wet for an appreciable increase though occurring in a light soil area it might be ideal. It comes well within the limits of three months' precipitation and temperature as shown in the figures in Table 1 of individual years preceding sawfly increase. Years slightly on the dry side of this average would be so near the optimum index that an outbreak would be expected while a wet year would easily throw this hythergraph into the form of that in Figure 2 which would reduce an outbreak condition.

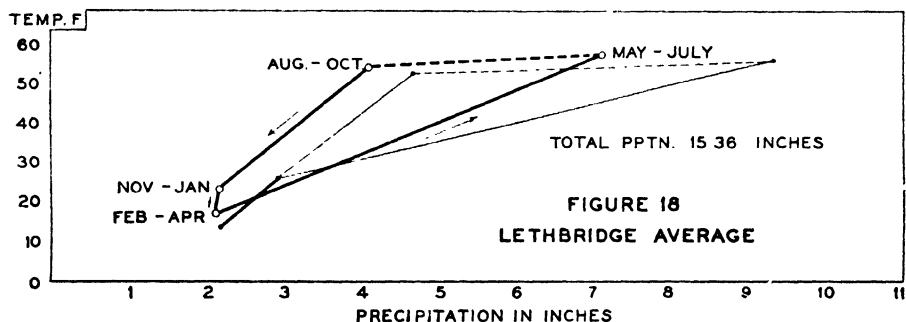
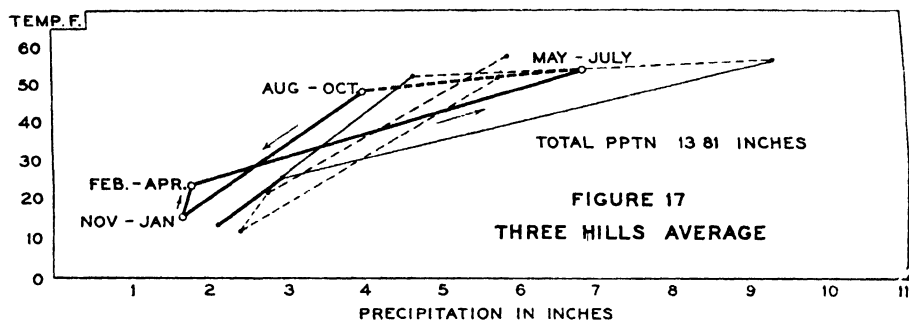
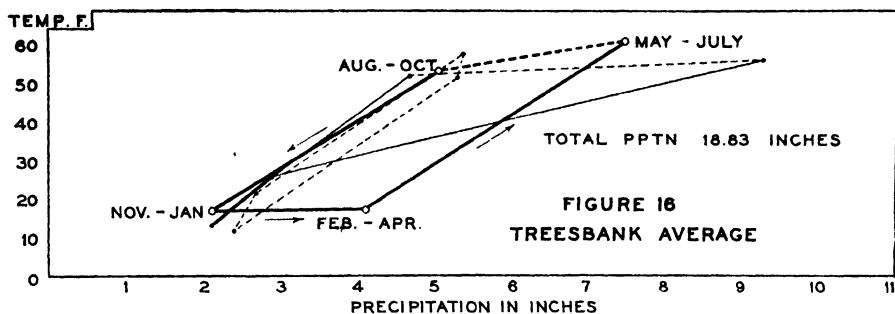
The limits of the present area where the insect occurs in economic numbers on the Canadian prairies are shown on the map. Thirteen points which have weather records covering several years were chosen as close to this line as possible. The average records were plotted to make the hythergraph as shown in Figure 15. Points within the dry area of south-eastern Alberta were purposely omitted from this average because they represent a particular condition not comparable with the area north and west of the present distribution. The hythergraph as shown in Figure 15 represents the average conditions within 60 miles of the present limit of infestation from Claresholm, Alberta, north, east and south to Emerson, Manitoba. The average climate of this surrounding area corresponds closely to the average conditions of the years which, within the area of heaviest infestation, precede a decrease in sawfly population as shown in Figure 2 (indicated on Figure 15). The fall precipitation and temperature compare very closely. The conditions for the period of May-July show a little more than 1 inch less precipitation but well over the lower limit of summer precipitation in individual years as shown in Table 2. It would require a series of years with unusually dry summers to bring the sawfly population up to economic numbers beyond the present area of infestation. On the other hand a series of years with summer precipitation above the average would force the present borders of the infested area back towards the area of greater infestation.



The average climate of localities within the area of greatest infestation may be unfavourable to sawfly increase and still not be such as to cause a serious reduction in numbers. The result would be a constant infestation subject to an increase of economic importance following a single favourable year. The average climate of Treesbank, Manitoba, as illustrated by Figure 16, is within the lower limits of conditions favourable to the decrease of sawfly population. In this sandy area the May-July precipitation is sufficient to produce a rank growth of the host plants, but the high mean temperature for the period would tend to minimize the cumulative effect of the precipitation. The result would be that in an average year the sawfly population for that district would fluctuate very little.

The average climate of Three Hills, as shown in Figure 17, while approaching the optimum index would have a tendency to cause a decrease in population because the heavy soil and lower mean temperature would increase the cumulative moisture. The small total fall precipitation is not favourable so that the average year in this locality would be more inclined to show a decrease in sawfly population than the average year at Treesbank.

The dry portion of southeastern Alberta presents an entirely different problem. The average climate of six points in this area has already been shown in Figure 3. While the sawfly actually occurs in this district north of the river it has never been of real economic importance. In the southern part of the area indicated by the double line on the map (Figure 13) the insect has not yet been found. It is possible that a few wet years may



produce conditions whereby the sawfly can gain a foothold here and push the spread westward in the south. The evidence as shown by the fluctuations at Brooks indicates that increase will be very slow and then only after a series of three or four very favourable years.

There is no reason why the sawfly should not spread somewhat farther into the southwest in Alberta and eventually be found in most of the area along the border from Coutts, Alberta to Emerson, Manitoba. The northern limit in Manitoba and Saskatchewan has almost been reached although small isolated localities may be found where the climate would be favourable for outbreaks. The western limit has almost been reached in Alberta north of Calgary. South of Calgary the sawfly should eventually reach the Lethbridge, Macleod and Claresholm area although it does not occur there now. This prediction is based on the average hythergraph of Lethbridge (Figure 18) which is fairly typical of this section of the province. The average year approaches the general average of unfavourable condi-

tions although the insect should be able to exist. A season of just moderately dry conditions during the May-July period would closely approximate the optimum index or at least reach the maximum moisture conditions of individual years as shown in Table 1. The May-July mean temperature is identical with the optimum index.

The large wheat growing section in the Peace River district of Alberta should remain free of economic injury from Western wheat stem sawfly for many years, in spite of the fact that traces of the insect have been found there in native grass. The average climate of that area is not favourable for increase and there is a vast area between there and the present limits of economic infestation which is very unfavourable. Any migration from the present area of infestation through the two or three hundred miles of unfavourable territory would be very slow if not impossible.

FORECASTING OUTBREAKS OF THE WHEAT STEM SAWFLY

The study of the climatology of the wheat stem sawfly introduces the possibility of forecasting outbreaks of the insect. Before this can be done, many factors and conditions must be considered. An increase in numbers does not necessarily mean increased damage. The former is apparently greatly dependent on the conditions of the previous year while the latter is a direct result of the conditions of the particular season. The infestation in the vicinity of Three Hills, Alberta, was very heavy in the spring of 1926. There was some loss throughout the entire area and in a few cases fields were completely cut by the insect. The next season the numbers were considerably reduced and the infestation though general was fairly light. A period of two weeks' wet weather in the fall prevented the farmers from cutting their grain on time, with the result that every stem containing a healthy sawfly larva was cut before the grain could be harvested. The cut stems were beaten to the ground by the rain and were a total loss. The general loss in the season of 1927 was greater than the previous year even though the sawfly population was considerably less.

The types of soil and their moisture storing capacities must be studied before accurate forecasting can be made. The light soils may receive a heavy precipitation which will drain through and have only a slight effect on the insect or host plants. Some heavy soils clog with a slight amount of rain and the subsequent precipitation runs off. The soil of the Three Hills area is filled with cracks of varying widths running several feet into the ground. Even though the surface soil is saturated with water there is seldom any run-off as the water works into the cracks and builds up a subsoil reserve, not affected by high temperatures.

The detailed study of the meteorological records of years preceding outbreaks shows that the precipitation for the period of August-October varies from 3.47 inches in the heavy soil area to 6.93 in the sandy area. The lowest mean temperature, 50° F., occurred with the lowest fall precipitation which would tend to increase the cumulative moisture. The highest mean temperature for this period was 58° F. and accompanied the highest precipitation; in the light sand soil this would reduce the cumulative moisture and bring it nearer the average.

The May-July precipitation varied from 3.28 inches to 6.74 inches. Both extremes occurred in the sandy soil area with only average mean temperature. The mean temperature varied from 57° to 64° F. The high precipitation followed a fairly dry warm fall and the majority of the spring precipitation occurred in May. This would tend to increase the reserve moisture without seriously handicapping the sawfly development. The low spring precipitation was assisted by a wet fall and heavy winter snow-fall so that the cumulative effect would approach the average.

The records preceding decrease in sawfly population have a fall precipitation varying from 2.08 inches to 8.44 inches and a mean temperature variation from 46° F. to 57° F. The heavy fall precipitation was followed by over 8 inches of summer rainfall which would produce very unfavourable conditions for the sawfly. The lightest fall precipitation which would result in uneven host plant development was followed by over 12 inches of early summer rainfall.

The May-July precipitation for years preceding sawfly decrease varied from 7.23 inches to 12.13 inches and the mean temperature for the period varied from 54° to 63° F. The lowest precipitation was accompanied by a very wet cool April, a dry cold May and a warm wet July. While April has not been considered as having very much influence, in this case the precipitation was over 5 inches. This, when followed by a cool May, would have the same cumulative effect as increasing the May precipitation.

A true forecast of sawfly increase or decrease for the Canadian prairies should be based on precipitation, temperature and soil moisture. With the limited data available, the soil moisture factor is eliminated for the present and the forecast is based on precipitation and temperature with consideration for the soil types.

In heavy soil areas the sawfly population apparently increases when the precipitation during the period of August-October of over 3 inches, accompanied by a mean temperature of between 50° and 58° F., is followed by a May-July precipitation of under 6 inches and a mean temperature of 57° to 64° F. The lower precipitation in either period must be accompanied by the lower mean temperature. If drought conditions are present there may be a decrease in sawfly population, provided the drought seriously affects the crops grown under all methods of cultivation.

In the light soil areas the sawfly population apparently increases when an August-October precipitation of over 4 inches, accompanied by a mean temperature of 50° to 58° F., is followed by a May-July precipitation of less than 7 inches accompanied by a mean temperature of 59° to 64° F. The lower precipitation in either period must be accompanied by the lower mean temperature, and the increase will be more marked if July is the driest of the three summer months. Drought conditions are more apt to be present in the light soil areas, and a precipitation of less than 4 inches during the May-July period accompanied by a high mean temperature may cause a marked decrease in sawfly population.

The sawfly population apparently decreases whenever the precipitation for the period of August-October of less than 5 inches with a mean temperature of 46° to 57° F. is followed by a May-July period with the precipitation over 7 inches and a mean temperature of 54° to 63° F. The lower temperature

must accompany the lower precipitation and if the fall precipitation is greater than 5 inches with a correspondingly high mean temperature it must still be followed by a high summer precipitation. This statement of forecasting apparently applies to the different soil types though it is probable that the totals could be lowered for the heavy soil areas with the same result.

Using these figures as a basis, several years have been chosen as showing a marked increase or decrease in sawfly abundance. The verification of the results has borne out the forecasting surprisingly well.

ACKNOWLEDGMENTS

The assistance of Mr. Norman Criddle⁴ of the Dominion Entomological Laboratory at Treesbank, Manitoba, and Mr. K. M. King of the Dominion Entomological Laboratory at Saskatoon, Saskatchewan, made this paper possible. Both have given freely of their observations and unpublished information. Reliable information on weather observations and sawfly fluctuation could not have been obtained from any other sources.

SUMMARY

The wheat stem sawfly (*Cephus cinctus* Nort.) is a native grass-inhabiting insect which has become a wheat pest of the Canadian prairies.

The adults emerge in June and oviposit in well developed stems of grasses and grains. The larvae spend the summer feeding in the stems. As the plants mature the larvae girdle the stems from the inside just above the soil surface. The stems fall to the ground and the larvae spend the winter in silken cocoons, in the cut stubs. Pupation takes place late in May.

Rainy wet weather in the spring affects the pupation and emergence of adults and a stormy June may kill some adults. The development of a few strong host plants in the spring results in a concentration of eggs in these plants. One larva matures in each stem after destroying all the other eggs and larvae. A fall precipitation which builds up the reserve moisture in the soil and causes an even development of host plants reduces the concentration of eggs and insures a greater number of larvae for the number of eggs laid. Heavy summer precipitation which produces a rank growth in the host plants results in many larvae being drowned in the sap which runs into the hollow stem from the larval feeding cuts.

The weather conditions during the crop year from August 1 to the following July 31 apparently affect the sawfly population for the next season. The two periods of August-October and May-July seem to exert the greatest influence on the host plants and the sawfly, and the influence of weather appears to be more of a cumulative effect of each period rather than the effect of separate months.

Hythergraphs have been constructed on a three months' cumulative basis and used as a basis of discussing weather conditions. These are used in correlating individual seasons and sawfly fluctuation as well as the climate of the prairies and sawfly distribution.

⁴ Deceased.

There appears to be a possibility of forecasting sawfly fluctuations with greater accuracy when the present information can be correlated with soil moisture investigations. At present a tentative forecasting can be made based on the precipitation and mean temperature for the periods of August-October and May-July.

REFERENCES

1. AINSLEE, C. N. The western grass stem sawfly. U.S.D.A. Bul. 841, 1920, Revised 1929.
2. CRIDDLE, N. Life Habits of *Cephus cinctus* Nort. in Manitoba. Can. Ento. 55. 1923.
3. CRIDDLE, N. The western wheat stem sawfly in Canada. Ann. Rept. Ont. Ent. Soc. 52. 1921.
4. CRIDDLE, N. The Hessian fly and the western wheat stem sawfly. Dom. Dept. of Agr. Bul. 11. 1916.

A BIOLOGICAL METHOD OF DETECTING THE PRESENCE OF FUNGICIDES ON SEEDS¹

H. W. MEAD²

Dominion Laboratory of Plant Pathology, Saskatoon, Sask.

[Received for publication December 7, 1944]

During the course of some seed studies in which the effect of the fungus, *Helminthosporium sativum*, on germinating wheat seeds was being studied, it was discovered that conidia of this fungus would not germinate near seeds treated with Ceresan. This is an organic mercury dust used on cereal seeds for the control of smut and other fungi. This observation led to the adaptation of this principle for the purpose of testing seed for the presence of Ceresan and, more particularly, for measuring coverage; i.e., the percentage of seeds which received a uniform covering of dust.

MATERIALS AND METHODS

The following procedure was followed in setting up the test. Agar was poured into Petri dishes, and when cool, it was inoculated by flooding with a heavy suspension of spores of *H. sativum* in water. Enough of the suspension was added to cover the agar, and any excess was poured off by tipping the Petri dish. The seed to be tested was placed on the inoculated agar immediately, with 5 seeds on each dish. The plates were incubated at 24° C., and they were read about 48 hours later. At this time it was seen that the fungus had failed to grow in areas, roughly circular, around the treated seeds; indeed, there was very little growth on some of the plates even at a considerable distance from the seed. Untreated seeds, however, were completely surrounded and often overrun by the mycelium of the fungus. (Figure 1.)

USE OF THE METHOD

When this method was used to test coverage by a seed-treating machine or other means, samples were taken at timed intervals as the seed was being treated. From each of these samples, about 20 seeds were taken at random and were sown on the inoculated agar. This showed the percentage of seeds receiving dust in any sample and indicated whether or not the dust was being applied evenly to the whole lot of seed.

The author has used this means to test various seed-treating machines and methods. The results of some of these tests, given in Table 1, showed considerable variation in the efficiency of certain machines and methods, and some fluctuation in the amount of dust applied to the seed.

¹Contribution No. 801, Division of Botany and Plant Pathology, Science Service, Department of Agriculture, Ottawa, Canada.

²Assistant Plant Pathologist.

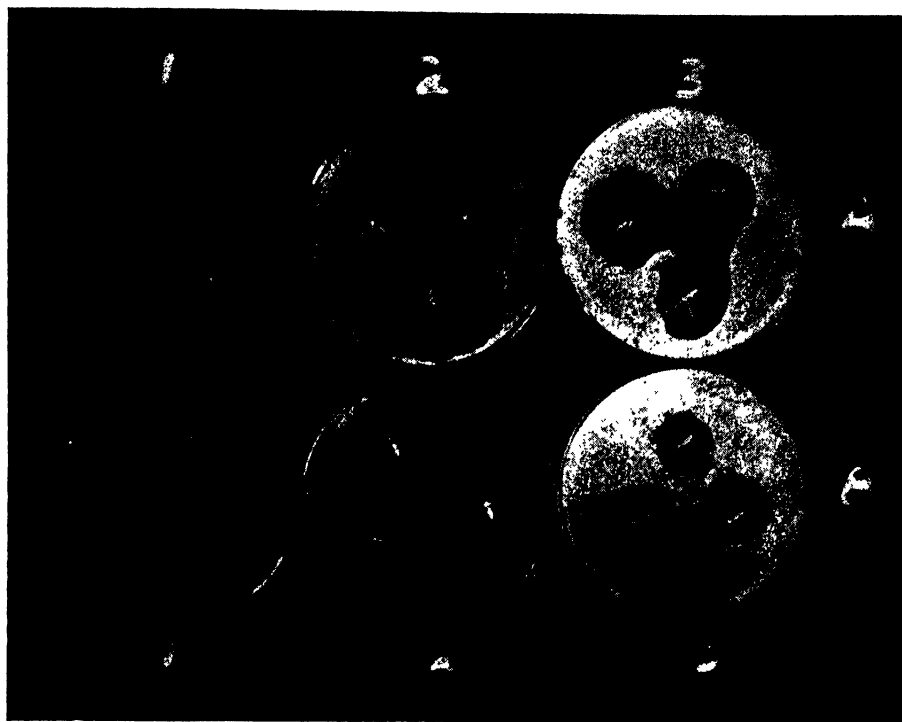


FIGURE 1.

TABLE 1.—SHOWING THE PERCENTAGE OF SEEDS DUSTED WITH CERESAN BY VARIOUS MACHINES AND BY THE HAND METHOD. THESE RESULTS WERE OBTAINED BY PLATING THE TREATED SEEDS ON INOCULATED AGAR

Method	Sample										Mean
	1	2	3	4	5	6	7	8	9	10	
	%	%	%	%	%	%	%	%	%	%	%
Machine No. 1	100	100	80	100	90	100	80	100	100	100	95
Machine No. 2	100	100	100	90	100	100	100	100	100	100	99
Machine No. 3	100	100	100	90	80	70	50	80	80	100	85
Machine No. 4	100	100	100	100	100	100	100	100	100	100	100
Machine No. 5	100	20	100	100	20	0	40	100	100	60	64
Machine No. 6	55	100	100	95	95	64	15	100	100	60	79
By hand:											
2nd mix	100	100	80	100	100	100	100	100	80	100	96
4th mix	100	100	100	100	100	100	100	100	100	100	100

Further tests to determine the inhibitive effect of other fungicides on *H. sativum* and other fungi, grown in the same manner on agar in Petri dishes, were conducted by Miss A. M. Dickey of the Plant Products Division, Saskatoon, while working temporarily at this laboratory. The results of these tests are given in Table 2.

TABLE 2.—SHOWING THE INHIBITIVE EFFECT OF VARIOUS DUST FUNGICIDES, CARRIED ON WHEAT KERNELS, ON THE GROWTH OF ELEVEN FUNGI FRESHLY PLANTED ON POTATO DEXTROSE AGAR AND INCUBATED AT 24° C.

Fungus	Check	Fungicide						Copper carbonate
		Ceresan	Leytosan	Semesan	Spergon	Thiosan	Arasan	
<i>Helminthosporium sativum</i>	0	+++	++	++	+	+++	+++	0
<i>Fusarium culmorum</i>	0	++	++	+	+	++	—	0
<i>Coniothyrium</i> sp.	0	+++	++	++	+	+++	+++	0
<i>Cephaosporium</i> sp.	0	+++	++	++	+	+++	+++	0
<i>Penicillium puberulum</i>	0	++	++	+	+	++	h	0
<i>P. lilacinum</i>	0	++	++	+	+	++	+	0
<i>Penicillium</i> sp. No. 100	0	0	+	0	+	0	0	0
<i>Penicillium</i> sp. No. 551	0	++	+	+	+	+	h	0
<i>Trichoderma</i> sp. No. 521	0	++	0	+	0	+	0	0
<i>Trichoderma</i> sp. No. 541	0	++	+	+	0	+	h	0
<i>Aspergillus flavus</i>	0	++	++	+	+	++	+	0

Legend:

- 0 = no inhibition
- +
- ++ = slight inhibition
- +++ = moderate inhibition
- ++++ = complete inhibition
- h = growth hindered but not prevented
- = no test.

It will be seen in Table 2 that inhibition of growth of several fungi, growing from a spore suspension newly placed on agar may be caused by several fungicides. Among these were three organic mercury dusts and three organic non-mercury dusts. All of the former class prevented germination and growth of most of the fungi. Of the latter class, thiosan had the greatest effect. Copper carbonate did not suppress any of the fungi. One species of *Penicillium*, isolated from wheat roots, resisted most of the fungicides.

CONCLUSIONS

It was found by exploratory tests that this method was very sensitive and that very small amounts of Ceresan could be detected on wheat seed. It is reasonable to expect that the other fungicides could be detected in small quantities also. The positive nature and sensitivity of the test makes it reliable in determining the presence of fungicides and the coverage on a seed sample. Its non-specificity prevents its use to determine the nature of the fungicide. With certain modifications, such as the use of uniform glass beads to carry the dusts, this method possibly could be used in the evaluation of fungicides, preliminary to extensive field tests.

SUMMARY

A biological test for the presence of fungicides on seeds is described. The basis of the test is the inhibition of growth of certain fungi on agar in the immediate neighborhood of treated seeds.

SOIL AND PLANT ANALYSIS. C. S. Piper, D.Sc. Interscience Publishers Inc., 215 Fourth Ave., New York 3, N.Y. 1944. \$4.50.

This book on methods of soil and plant analysis is probably unique in that plant analysis is given a place in a text which deals so fully with physical and chemical analysis of soils.

As the author states, the methods outlined in the text have been fully tested at the Waite Agricultural Research Station, and furthermore a wide variety of soils has been used in checking the validity of the results by the different methods.

The book provides the laboratory worker with a most comprehensive discussion of almost every determination he is likely to encounter in the analysis of soil or plant material with the exception of "available" methods. In regard to the latter, the author feels that none of the many proposed methods has gained general acceptance and therefore is not included in the text.

The inclusion of a section on plant ash analysis in a text book dealing quite fully with analysis of the soil appears to be an excellent provision. Nearly every technician or investigator finds it necessary to carry out some form of ash analysis at one time or another. It is an undoubted convenience to have the methods of plant analysis gathered within the same cover as procedures for the analysis of soils.

In addition to considering methods adapted to the determination of the more common mineral elements in plant ash, attention is also given to the matter of determining trace elements.

All in all, Piper's *Soil and Plant Analysis* appears to be a timely and valuable contribution to the subject. Workers in this field should find this a useful text for reference and a convenient source of information on methods they may not have had occasion to become familiar with previously.

J. MITCHELL.

ERRATUM

In the article entitled, "Topography and minimum temperature" by W. D. Albright and J. G. Stoker, November 1944 issue of *Scientific Agriculture* (Vol. 25, No. 3, p. 151), there is an error in Table 3, second column under No. V. The figure for the year 1938 should be 0.96 instead of 0.06.

A MILKWEED SURVEY IN ONTARIO AND ADJACENT QUEBEC¹

H. GROH² AND W. G. DORE³

Science Service, Ottawa, Canada

[Received for publication, February 1, 1945]

Revival of interest in common milkweed (*Asclepias syriaca* L.) as a possible source of substitutes for products curtailed by the war was the occasion for the present survey activity

The Dominion Government in 1942 instituted a search for native sources of rubber and other materials needed in the existing situation and, finding milkweed a promising species, proceeded to secure a quantity of the seed through the agency of co-operating schools in Carleton County adjacent to Ottawa. In 1943 land in Peterborough County, as well as at Ottawa, was seeded to milkweed; and a campaign for the harvesting of "wild" leaves for use in a pilot plant at Ottawa, experimentally producing milkweed "rubber," secured its immediate needs from collectors all over the province and beyond. In 1944 the demand was altered to pods, desired for their floss, to meet urgent requirements of a good substitute for kapok in providing life jackets for sailors and airmen. All the foregoing presupposed that milkweed in some quantity was, or could be made, available.

The general distribution and incidence of the plant was already known from data accumulated in the files of the Canadian Weed Survey over a period of some twenty years. This information, together with what could be gathered from various Canadian herbaria, has been published (1) but may be reviewed briefly here.

Common milkweed was found to be growing in all provinces from Saskatchewan eastward with the exception of Prince Edward Island and, until fairly recently, Nova Scotia. Its distribution westward from Ontario is interrupted north of the upper Great Lakes but not directly westward through Michigan; and the United States range continues southward even, according to some, to Florida, Texas and Arizona. Through much of this broad extent it is not sufficiently abundant for large scale exploitation. In Canada, east of Quebec city, west of Lake Huron, and north of Old Ontario the incidence is not high, occurrence being only in scattered patches, thin stands, or more often northward, not at all.

It was, then, within the southern portions of Quebec and Ontario that a more detailed survey, particularly for density, was required. Certain regions of higher incidence along an axis across Ontario had been indicated,

¹ Contribution No. 808 from the Division of Botany and Plant Pathology, Science Service, Department of Agriculture, Ottawa, Canada.

² Associate Botanist.

³ Seasonal Agricultural Assistant.

but fuller and more quantitative data were still needed for intelligent direction of campaign effort as well as for the best possible understanding of habitat and other growth requirements of the plant. During 1943 and 1944 the available time of the joint authors was used in an attempt to spread as uniform and adequate a network of survey lines over Old Ontario as was possible under current transportation limitations. This was extended northward and eastward into Quebec, but not sufficiently to warrant inclusion here except for some portions along the Ottawa River.

THE SURVEY

In any survey of such a large area some sort of random sampling method must be used. To this end efforts were made to traverse as many townships, or at least counties, as possible. Travel was by train or bus and by automobile. Auto travel allowed scrutiny of both sides of the road and the adjacent fields. By train one side only was recorded regularly although general impressions of fields opposite were gathered. Speed of some trains detracted from, but seldom wholly prevented reasonably satisfactory work.

Milkweed, being a tall and conspicuous plant (Figures 1 and 2) was amenable as many others would not be to this type of running survey. The species with which it was most likely to be confused at a distance were such as elecampane and low shoots of choke cherry. Concentration on a single object of survey permitted attention to density which was not possible in the earlier surveys covering hundreds of weed species at once for mere listing. In those circumstances an idea of incidence, derived from computation of the percentage of surveys in which milkweed appeared, was the primary objective.

The routes followed in the course of the Ontario surveys during the two summers are shown in Figure 6. Observations were made over a total of 5,860 miles, travelling 4,598 by automobile and 1,262 by train or bus. In Quebec adjacent to the Ottawa River 272 miles were travelled by automobile. It is clear that the survey even now is not exhaustive although distance from a line of travel is nowhere very great. Parts crossed in reaching others more remote were inevitably worked the more closely as, for instance, Nepean Township next to headquarters, in which scarcely a road was left untravelled. This resulted in data based on uneven amount but still quite comparable character of survey. Whatever selection there was of routes for auto travel aimed to use both primary and secondary roads and to reach the various parts of a municipality. Roads along political boundaries were avoided since estimates here required extra calculation to share them fairly between contiguous townships.

Method of Estimation

In actual practice methods were evolved for separate recording from two distinct types of site: (a) along roadsides and railways stands of varying density, on belts from road shoulder to fence strip, of varying width especially when reduced by shrubbery, water or rock exposure, were more or less continuous and lent themselves to linear rather than area recording as they passed under view; (b) field stands within easy range



FIGURE 1. Milkweed in flower is an attractive and distinctive plant. Of the numerous flowers going to make an umbel only a few mature as pods. These plants grew on the soil of an upland outcrop of crystalline limestone in prevailingly Laurentian gneiss at Lascelles, Gatineau Co., Quebec. (Photo by E. G. Anderson).

of vision beyond fence strips tended to be discontinuous owing to differences of land utilization in successive fields, woodland cover or drainage, and when present in enough area and density were recorded on an area basis.

Concepts of density first had to be established. Five grades from practically "absent" to "good" were found of practical value for use at a moderate rate of travel. Numerical equivalents for each of these were arrived at by counts of numerous stands that were considered representa-



FIGURE 2. Roadside plants are often vigorous and highly productive. These dust-covered plants bear respectively 17, 21 and 14 developing pods per stalk. This is a region of clay soil, $1\frac{1}{2}$ miles east of Stanley Corners, Carleton County. The plants are growing along the shoulder of a dirt road next to a deep ditch. Other plants have been grazed down. (July 31, 1944).

tive. These are shown in Table 1 and in part illustrated in Figures 3, 4 and 5. For roadsides these were obtained by counts of all stalks in a roadside strip measured as to length, but merely average as to breadth. For field stands the count was of all stalks in a belt transect paced 70 yards long and 1 yard wide by sight, or approximately $1/70$ th acre in area.

Usually several transects in representative positions in a field were averaged to get a fair equivalent for the density given. The numerical equivalents so derived were used in all subsequent calculations.

TABLE 1.—SCHEDULE OF GRADES USED IN THE ESTIMATION OF DENSITY OF ROADSIDE AND FIELD STANDS WITH THEIR EQUIVALENTS IN NUMBER OF INDIVIDUAL STALKS

Density grades	Roadside stands (stalks per mile)		Field stands (stalks per acre)	
	Range	Average	Range	Average
Absent	0 to 50	0	0 to 100	0
Poor	50 to 700	300	100 to 1,000	500
Sparse	700 to 3,000	1,500	1,000 to 5,000	2,500
Medium	3,000 to 8,000	5,000	5,000 to 10,000	7,500
Good	Over 8,000	10,000	Over 10,000	15,000



FIGURE 3. A roadside stand with 95 stalks in the strip about 2 yards wide and 1 rod long, equivalent to 30,000 stalks per mile, $1\frac{1}{2}$ miles west of Fallowfield in Nepean Township, Carleton County. The larger plants are about 3 feet tall, producing from 8 to 22 pods each or an average of 12 pods per stalk. The soil here is heavy, the plants growing on the well-drained shoulder above a wet ditch. This patch would be rated as "good" density, however, the whole strip along this road was graded "medium" on account of some thin stretches.

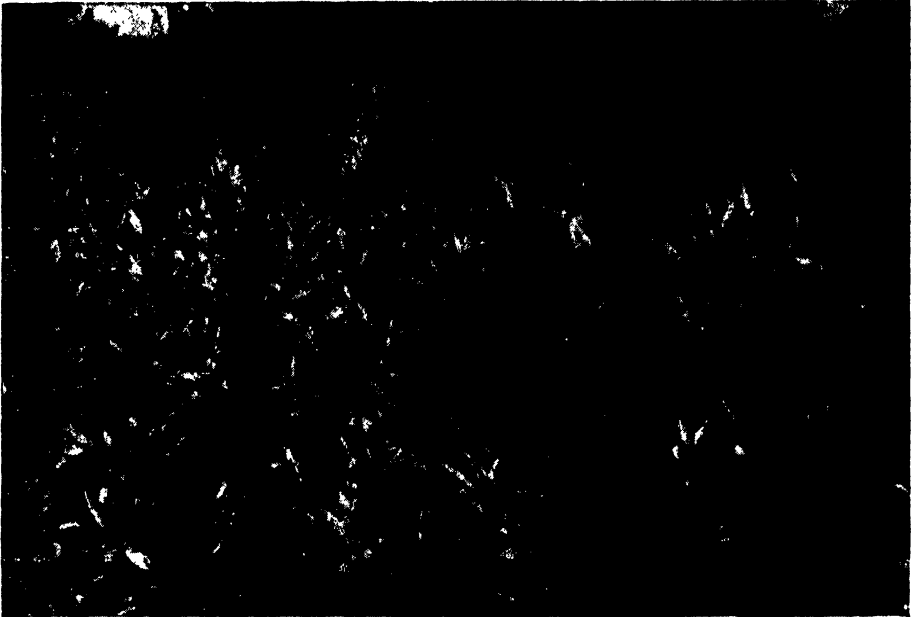


FIGURE 4. A wild stand of milkweed on the heavy clay soil at Fallowfield Station near Ottawa. This field of about 6 acres in extent, has at times been cultivated, used as a meadow, and this year heavily grazed. Counts gave 19,250 stalks per acre, a high ("good") category of density. About 1 stalk in 20 is bearing pods on the average of about 6 per stalk. The roots are shallow, only about 2 inches deep on this soil, under a sod of timothy, couch grass and perennial weeds.



FIGURE 5. Milkweed in a pasture field at Ottawa along the Rideau River. This stand would be rated as "medium" density. It has been pastured for many years.

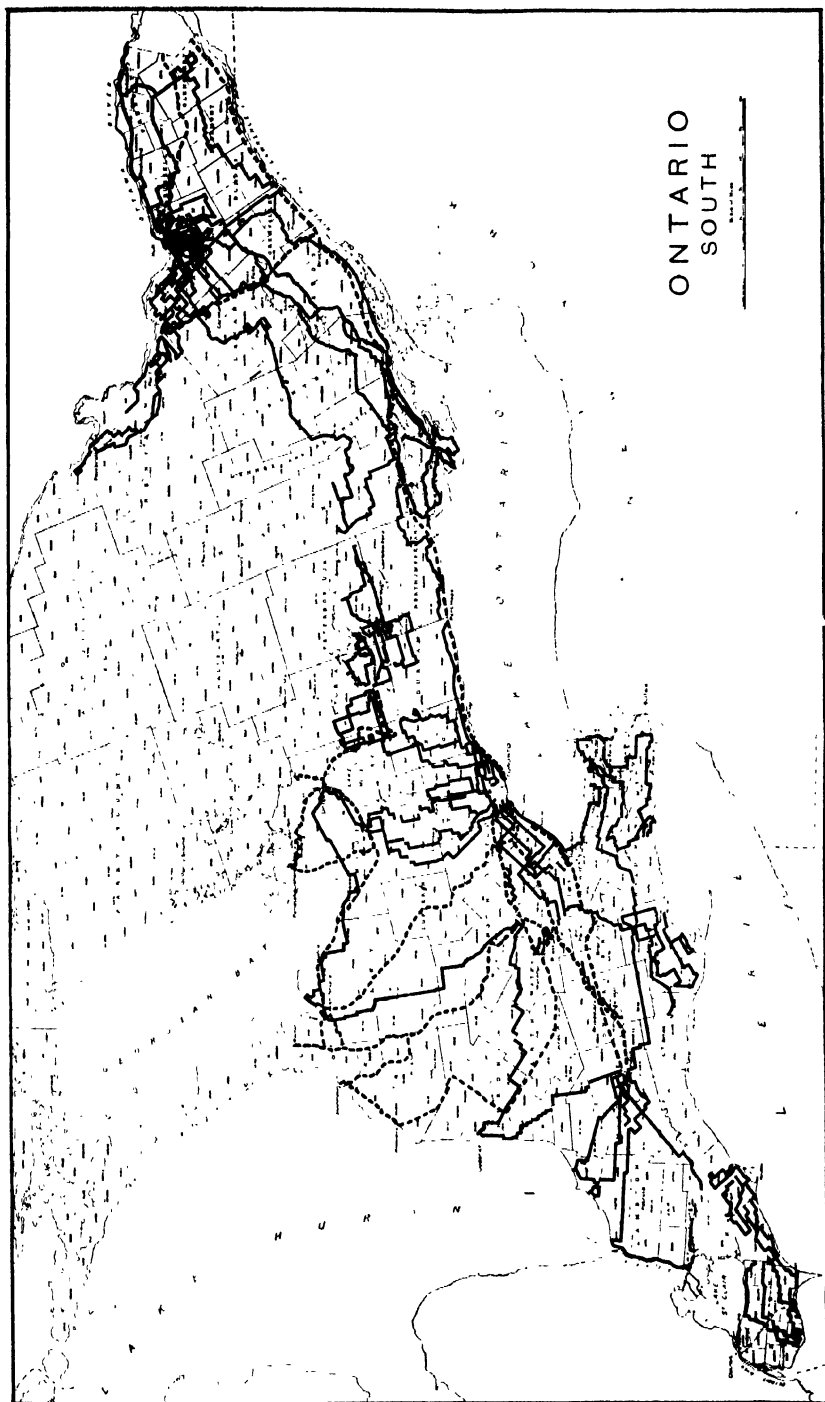


FIGURE 6. Survey routes in Ontario. Routes traversed by automobile are represented by solid lines; train and bus by broken lines.

Observations were recorded on maps carried along or in part in notebooks. Sheets of the National Topographic Series of the Department of National Defence, scale 1 mile to 1 inch, were used folded conveniently to receive entries delimiting each change of roadside density as passed by and locating field stands. From these roadside entries the various densities were later coloured in permanently according to a scale of colours adopted. They were then ready to be measured in miles of each by means of a calibrated wheel and summarized by townships. Field stands, indicated as to position on the map by a numbered circle, were at the same time entered in a notebook to show judged acreage, density grade and character of the habitat.

From these two sets of data the desired single figure for stalks per mile from roadside and field stands was obtained by addition. Then, dividing by the number of survey miles, a relative figure was obtained which made possible a comparison of one with another regardless of its size or the number of miles travelled. For the township or other unit adopted, these relative figures could then be arranged in descending order of density and grouped into the five grades shown in the legend of Figure 7. It is to be noted that the limits of these groups do not necessarily correspond with any of those in Table 1 but were derived more or less arbitrarily to put about an equal number of townships in each.

As mapped by townships, centres of high, diminishing outward to lower densities, are apparent. A generalized presentation in Figure 8 serves to blend townships missed entirely with those adjoining, and to focus still more the results obtained. Local extremes due to inadequate sampling are smoothed out in accordance with judgments based on personal knowledge of the situation or on replies to questionnaire enquiry.

MILKWEED POPULATIONS

Coming to a scrutiny of the map figures it can be seen that in Ontario (including Quebec parts of the Ottawa Valley) there are three major concentrations of milkweed. That in eastern Ontario, roughly the Ottawa Valley, is segregated from the others rather sharply by the wooded Laurentide shield on the northeast, and the rugged Frontenac axis of the same Precambrian formation reaching south to the Thousand Islands of the St. Lawrence. To the west, from end to end of the Trent Canal zone and north of the narrow lake plain, concentration is high. In the remainder of the area surveyed the most significant feature uncovered appears to be a paucity of milkweed from almost the whole plateau above the Niagara escarpment line to the Bruce Peninsula and extending to the St. Clair flats and Erie shore, where another concentration of milkweed occurs. Below the escarpment, the level land north and west of Toronto, and the Niagara fruit belt, are also sparse. The dearth of milkweed in this region was especially notable in some of the heavy soils encountered. To a remarkable degree, also, there is conformity with earlier geological shore lines of the Great Lakes. Further analysis of this and other factors should be profitable, although perhaps, only after still more critical surveys. A fourth zone, of less extent, on either side of the city of Toronto is to be noted.

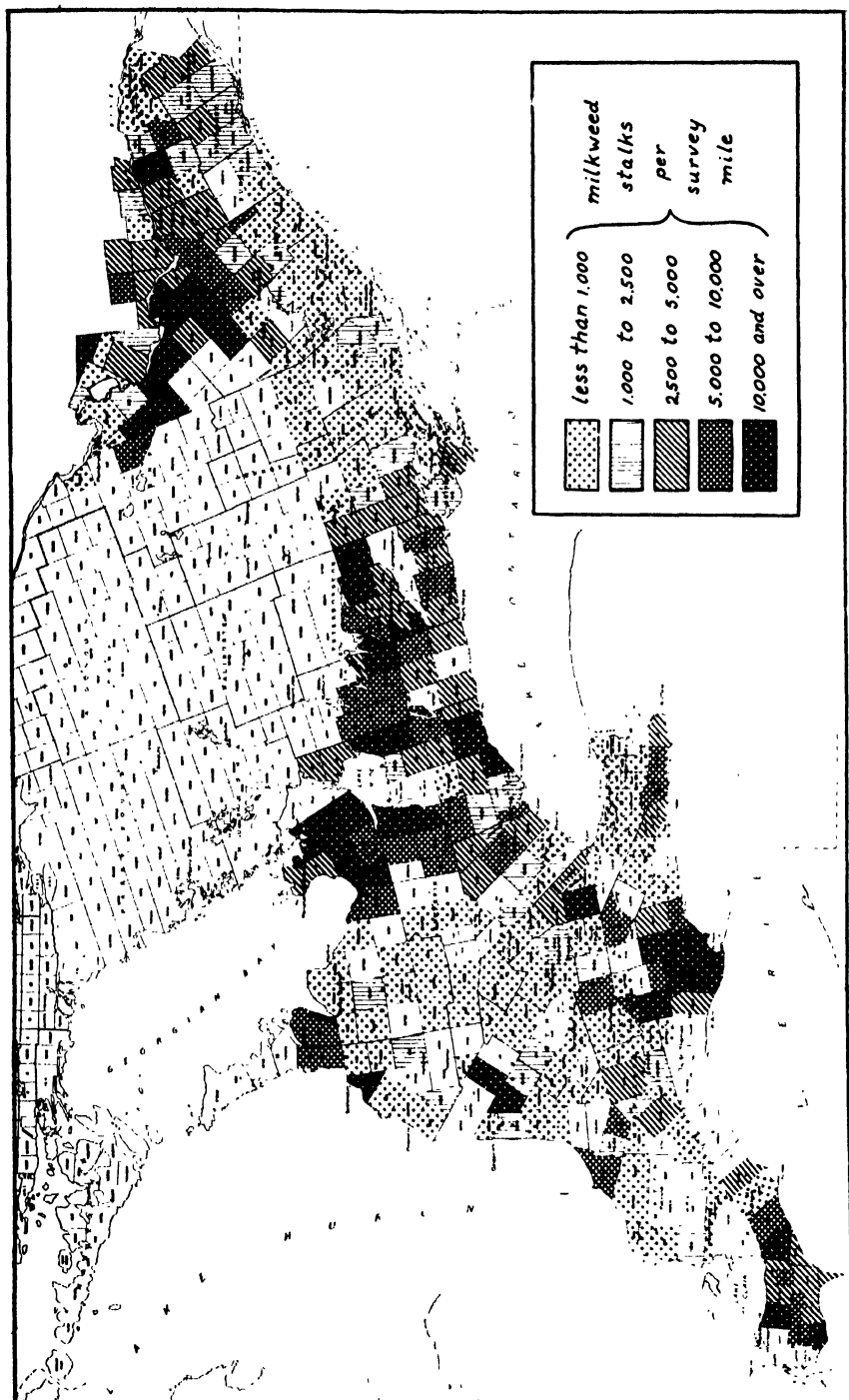


FIGURE 7. Milkweed density by townships based on averages of roadside and field stands as observed while travelling routes indicated in Figure 6. Unshaded townships were not traversed.

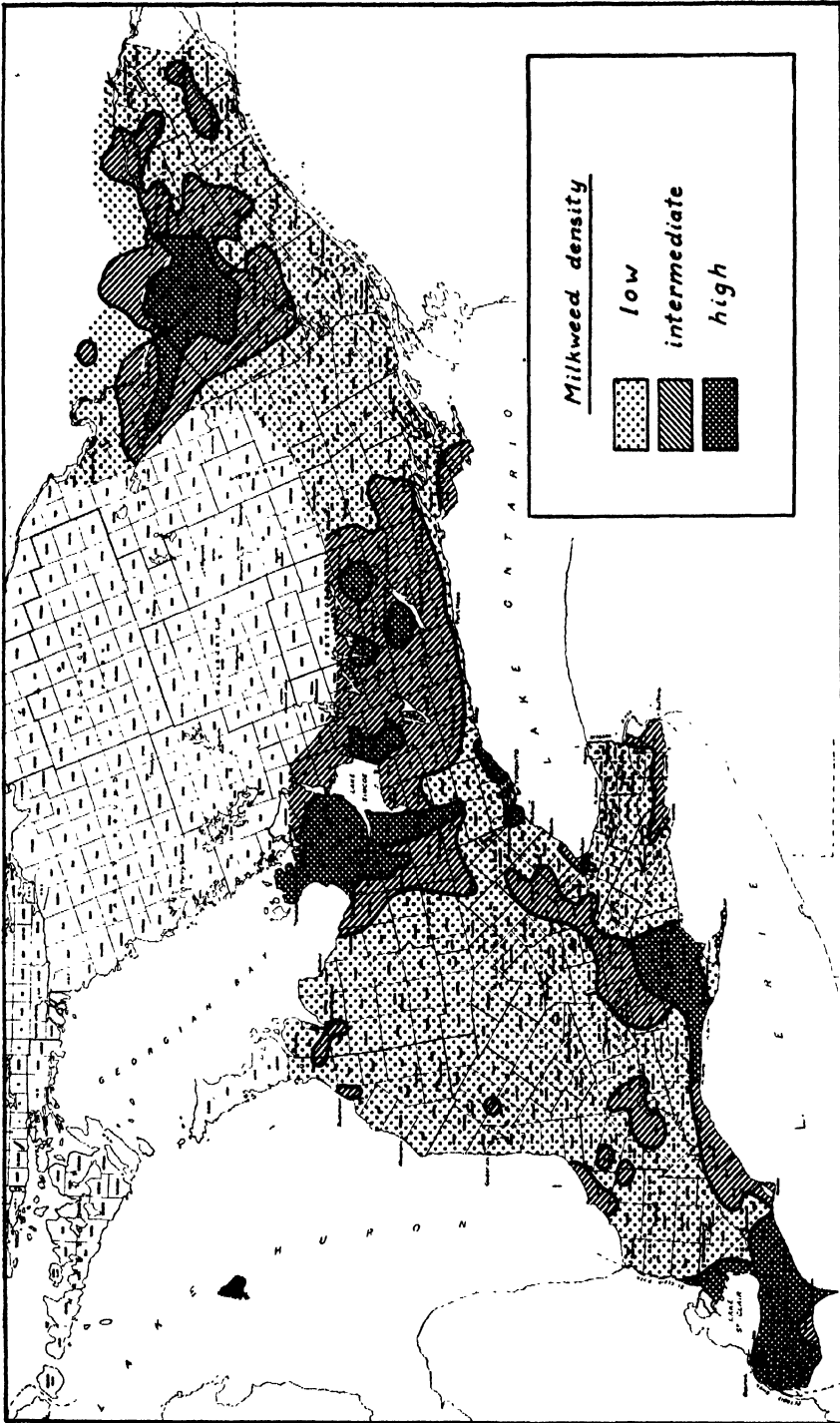


FIGURE 8. Generalized map of milkweed populations of various densities based on the township averages as indicated in Figure 7.

Some faults inherent in the sampling method may be pointed out which, while not affecting seriously the broad outlines, have a bearing on the more local applications. For instance, the border townships along the Detroit River, central Lambton County, and the greater part of Elgin's narrow strip were missed in the survey, and in the generalized map had to be merged with adjacent findings in the light of probability. Again, Morris and Hullett Townships in Huron County are an example of how a concentration of about 35 acres of milkweed around the town of Blyth, situated on the boundary between them, could create a "high" for two townships not in keeping with what was found for the region generally. A similar instance is afforded by Rockland in Russell County, and others in various places both East and West. When sampling is represented by an insufficient number of survey miles a single large field of milkweed can throw the stalk averages out of proportion to the general density over the area. In other cases, as in Canboro Township of Haldimand County, and Wilberforce Township, Renfrew County, the averages, based on observations along marginal strips, are not truly representative. Moreover, it is felt that the results in an area like North Simcoe might be interpreted more conservatively than they were in view of the fact that more than usual of these dense stands were of dwarfed and sterile plants. The survey recorded stalks regardless of vigour or productivity.

DISCUSSION OF DISTRIBUTION

The rather striking segregation of milkweed populations in Ontario into three distinct regions, and these already foreshadowed in the preceding weed surveys (1), provides a starting point for consideration of factors which could be responsible. No simple hypothesis proves to be adequate throughout but several things are at least contributory.

Topography and Drainage

While topography varies only within rather narrow limits the following physiographic features can be distinguished: (1) lowlands of the St. Lawrence and Ottawa rivers; (2) Frontenac spur and Laurentian shield north of Ottawa Valley; (3) plain between Frontenac spur and Niagara escarpment, including a rough glaciated region of deep morainic deposits through Peterborough to Simcoe County; (4) plain above Niagara escarpment in places exceeding 1,000 feet above sea level, but including flat lowlands to the southwest. Thus it is seen that the three milkweed belts are comprised within two of these tracts and the least elevated part of the third, while the greater part of the western Ontario peninsula and the Frontenac axis lie between them.

Altitude, as such, need not be stressed as a factor as the drainage basins concerned seem to be of more significance. Some of the lowlands which are sandy, as the lake shore deposits in Essex County where milkweed populations run from 10,000 to 20,000 stalks per mile. in western Norfolk and extending into Elgin County, in Welland County along the shore, on the Lake Huron shore, and the Lake Ontario shores at Hamilton Bay and in Prince Edward County, are all well enough drained and support milkweed. But more generally lowlands are level, clay lake sediments, and are poorly drained unless of loose alluvial deposits or when served by

drainage canals. Apart from such exceptions they are deficient in milkweed, as very commonly in northern Essex and Lambton Counties, north and east of Toronto, and in much of the lowlands west of Montreal.

Uplands are of irregular topography with irregular drainage. The drumlin region in Durham, Northumberland, Peterborough, and Victoria Counties, and the morainic deposits west of Lake Simcoe give a great variety of soil and drainage types with many of them favouring milkweed. On the other hand the equally irregular Frontenac spur and Laurentian uplands, with their numerous lakes, are not generally favourable to milkweed, but for other reasons than drainage. The elevated plateau of the western Ontario interior is a flat and heavy terrain almost devoid of milkweed. Topography, as influencing drainage, undoubtedly has significance.

Climate and Drainage

Precipitation in these parts of Ontario is mostly between 30 and 40 inches annually. Small areas in the Ottawa Valley, between Georgian Bay and Lake Ontario, and at the extreme southern tip of Ontario receive less than 30 inches annually. These, roughly, are areas of milkweed abundance. The correlation may be mere coincidence, but it is of interest to note that the plant has an eastern limit of abundance toward the more humid climate of the Maritime Provinces. To the west common milkweed extends into eastern Manitoba in the zone of 20 to 30-inch precipitation, mostly in stream valleys where soil moisture is assured, but only sparingly beyond at less than 20 inches. There showy milkweed (*Asclepias speciosa* Torr.) and dwarf milkweed (*Asclepias ovalifolia* Dec.) largely supplant it.

As altitude was not, probably, the significant feature in topography so precipitation within broad limits would seem to be less important than soil drainage. At each of the three points with slightly less precipitation, drainage happens to be generally satisfactory. On the clay plains of western Ontario, and even on Rubicon sand in Russell County in eastern Ontario, both poorly drained because of level topography, milkweed is almost absent. For a part of the season these clay soils are wet almost to the surface (when not artificially drained) and root growth is forced to shallow levels. Droughts following, opening up soil cracks, both injure roots and deprive them of water. The species is not averse to moisture but must have sufficient soil aeration. The thick horizontal root apparently cannot endure a water-logged condition. In deep sandy soils the same trouble can be encountered in abnormal seasons when, as in the very wet August of 1943 with 9 instead of the normal 3 inches of rain at Ottawa, plants with roots growing deep in the open substratum were found killed in September, presumably through the raising of the water table above the level at which they had established themselves. It is a general observation that saturated swamp soils do not support milkweed although the well-drained road grades crossing them may be covered profusely. Once only did there appear to be a serious exception to the rule: at Walkerton, in Bruce County, seepage from a dam, keeping lower ground permanently in a state of moisture to maintain typical swamp vegetation of alder, willow and the like, included with them a fair amount of milkweed. It was growing, perhaps in competition for light, to record heights of 6 and 7 feet and bearing pods normally. Investigation probably would have disclosed

shallow-rooting reaching into hummocky spots to escape the saturation just below. In this situation too, there would not be the violent changes of water level involved in the other instances cited; fluctuation, seasonally or from year to year, rather than a higher or lower uniform level (above saturation) appears to be the critical factor.

Soils

On the whole there is considerable support for the view that soil moisture and drainage are of consequence. Whether soil itself (its texture, structure, acidity, fertility, etc.) is important has not been easy to determine. Relationships have not been clearly worked out because soil maps were not everywhere available and the survey is still too general.

Excellent stands of milkweed are to be found on soils of any textural group—sand, clay or muck, particularly when they tend to a loamy character, and providing they are well drained. The plant seems responsive to fertility. When sands are leached of fertility the plants, although present, are not luxuriant. This was apparent on sandy ridges and plains in Simcoe County and on extensive tracts near Otter Lake, in Pontiac County, Quebec. On the other hand when fertilized, even with commercial fertilizer as in the sandy tobacco fields of Norfolk County, stands were strong, where otherwise not so. Clay soils are naturally more fertile but, as illustrated in northern Essex County and up the Ottawa River, are productive of milkweed only when well-drained and agriculturally fit. Some of the best milkweed seen, in the Ennismore and Ipperwash districts, was on land approaching the muck type, which had undergone drainage and amelioration to a state of high fertility. Confusing the issue, though, is the fact that frequently in the Ottawa district fields of well-podded milkweed can be seen on almost bare, irregularly eroded limestone strata, the stalks emerging from deep fissures of the rock about as well as from the pockets of soil forming in every depression. Just what is the provision for moisture here is not clear, unless efficient root storage carried the plant through intermittent drought.

Soil derivation and the influence of underlying rock is of interest. Limestone is frequently, in eastern Ontario, quite shallow under flourishing stands of milkweed, and underlies much of its territory also in central Ontario, but that at the lower extremity of the province grows on lake deposits of considerable depth over the underlying Devonian limestones and shales. Outcrops of crystalline limestone within the Precambrian formation are also commonly milkweed areas. Only for the exception of southern Ontario this might argue limestone or alkaline preference of the species, but tests made of acid tolerance varied between pH 6.6 and pH 5.7, or scarcely neutral. More acid soils such as would be derived from granitic rocks, or from sandstone or clay soils sour from poor drainage, are definitely uncongenial. Soils of limestone origin on the other hand, are not necessarily highly alkaline, since leaching in a climate such as this ordinarily reduces them to near neutrality or even to acidity. The milkweed concentrations near Ottawa and in central Ontario are both on predominantly neutral soils. Roadsides, otherwise acid, are doubtless often rendered congenial to milkweed by pulverization of the limestone material applied to roads.

Absence of milkweed from certain shallow soils over level limestone strata in Prince Edward County and adjoining Frontenac County, and around Ottawa, might be attributed to their lack of moisture-holding capacity between rains, rather than to any unfavourable pH due to proximity of the limestone.

Light

Only rarely has milkweed been found in shaded conditions. Over most of the surveyed area cleared and wooded portions are fairly uniformly interspersed in the proportion of 20% (or less in Old Ontario alone) of woodlot to 80% of cleared or grass and marsh land (Census, 1931), and milkweed was notable only for its scarcity through these wooded stretches. Through the Lennox-Frontenac hinterland this would share with the granitic forest floor in responsibility for the dearth of the plant. In diffused light it may struggle upward into lanky growth, but more dense shade dwarfs it and soon extinguishes life.

Cultural Considerations

Under this broad head may be reviewed most of the man-made conditions which undeniably enter into any appraisal of the situation. It is generally conceded that *Asclepias syriaca* is native to North America, although originally it would be less widely distributed than now. Forest cover and water-saturated soils in pre-settlement times were the restricting factors to a greater degree than now. Savannah openings in the forest, sandy river flats and shore dunes and the plains westward would be the probable sources populating its present range. Certain observations of the survey suggest that migration eastward is still in progress. In the Eastern Townships of Quebec a tendency to isolation in pure clones along roadsides, in orchards and hay fields, rather than in pasture and roadside stands of continuous and intermixed clones, as in Ontario, might be interpreted as indicating recent establishment. Farther east, while there are early records from Quebec city, Matapedia, Fredericton, etc., others of the comparatively few and localized infestations are probably more recent. In Nova Scotia the plant was unknown until 1930, since which date almost an axis of stations has been stretched through the Annapolis Valley, with a report from Cape Breton. There are still no records from Prince Edward Island and the mainland opposite.

Climatically, and with regard to the other factors discussed, all of settled eastern Canada should come within the bounds of milkweed tolerance. It appears merely a matter of time and the operation of requisite agencies of dispersal to bring much of the remaining area under invasion. It may be doubted, however, that either here, or again in Ontario, will invasion be such as was depicted in a paper read by Alexander Kirkwood before the old Ottawa Natural History Society in 1867 when he said: "The milkweed is well known to almost every farmer and next to Canada thistle, is viewed by him as his greatest pest."

Kirkwood's picture may be less overdrawn than might be thought. If it is remembered that the best of Ontario farm lands must have passed through the cruder phases of development which still mark areas of marginal utilization owing to their topographically broken and less arable character,

the situation will be clearer. Forgetting for the moment altitude, precipitation, soil, and even drainage and light conditions as separate factors, a glance at the maps will reveal considerable association of high milkweed density with agricultural conditions only fair to marginal. Much of eastern Ontario's "high" is over shallow rock outcrops as contrasted with the less broken St. Lawrence lowlands east of there. The Trent Canal system is much less amenable to high tillage than the broad stretches of farm land north and west of Toronto. Above the Niagara escarpment, again, is a tract of more than 14,000 square miles, mostly under highly developed agricultural use, with milkweed at its best only in the sandy parts of Norfolk and Essex Counties devoted to tobacco growing under heavy reinforcement of artificial fertilizers, or even withdrawn from cultivation for reforestation. The point is that flourishing land use, whatever else may be conducive to milkweed, holds it in check, or strikes a balance between tendencies at least. As land clearance admitted, so agriculture finally stabilized the weed at its present more or less innocuous state in this or that belt.

As a corollary to the foregoing the suggestion is offered that any prospective demand for milkweed products should look, not to lands already well enough utilized but to those less favourably placed as regards crop adaptation, accessibility to markets, or under other disabilities of the "back concessions." Having now more than their share of milkweed let them capitalize on it. Extensive areas between Peterborough and Georgian Bay, for instance, with dwarfed and largely sterile stands on land furnishing indifferent pasture would, there is reason to believe, be stimulated to heavier production of this plant (and grass) by means of sharp surface scarification of disc or cultivator in spring or after soaking rain. In some cases ploughing would be a warranted expense, judging by numerous instances where incipient stands from roots, almost suppressed in old sods, have been found restocking promptly those parts broken up for potatoes, buckwheat or other grain. Any programme of milkweed increase should consider well the merits of such root propagation before embarking on little understood seeding operations on better land.

With further reference to pastures it may be doubted that grazing has much direct controlling influence on milkweed. The trampling of live stock and consequent firming of the soil no doubt retards it somewhat. Sheep are reported to eat the young plants, and some "topping" was observed in a Gatineau County, Quebec, pasture carrying young cattle. Ordinarily, animals graze closely around, without touching, milkweed stems. Plants dried in hay, on the other hand, are reported by Michigan observers to be much relished. On the whole lands in permanent pasture, more than in any other use, were the sites of heavier infestation, in eastern and central Ontario particularly.

Before leaving the subject of man-made conditions attention should be drawn to a distinct concentration of milkweed commonly in the neighbourhood of towns and cities. Land previously well farmed, under the influence of rising property values, reverts to weeds and grass in subdivisions awaiting use as building sites; and meanwhile provides the zone of density which has enabled schools of suburban Toronto and other centres of population to share fully with more rural districts in the harvesting of

leaves or pods. This is clearly shown east and west of Toronto in Figure 8. The same effect northward is neutralized in the mapping by the inclusion of so much land still attractive for intensive agriculture. The contrast between the more settled shore strip through Scarboro and on into Ontario County, and that inland through Agincourt, is at least partially thus explained.

The cycle of change from cultivation, through weeds and thin grass, to a closer sward is illustrated also in the roadside surveys. Secondary and less used roads, where weeds and infrequent mowing leave debris to prevent formation of a close sod, were appreciably richer in milkweed than main travelled highways, whether these were seeded down or merely allowed to grass over with the help of closer attention. In several years' history of a meadow the same decline of the plant upon the formation of denser sward has been observed. Railway embankments, and rights of way cleared of rubbish by frequent burning were usually characterized by open sod frequented by milkweed.

Other forms of life, as insects and disease organisms, attack milkweed, but can hardly be credited with any great influence on either density or incidence. Virus disease, everywhere prevalent, results in a dense clumping of stems throughout the extent of the clone infected, together with yellowing or mottling, and finally deforming of leaves, stems and flowers, and little fruiting. Flagellates are reported as occurring generally in the latex of normal plants. In Renfrew County in a vigorous crop of milkweed, whole clones up to several square rods in extent were being defoliated prematurely by what was suggestive of bacterial disease. Aphids were often abundant rendering the plants sticky with their exudates. Two leaf-eating insects were common, and once a gregarious species of hairy caterpillar had nearly stripped the foliage. In one instance white grub injury to the root was found to be the stimulus to proliferation of shoots similar to that present with virus troubles. The milkweed caterpillar, larval stage of the familiar Monarch butterfly, is not the factor in defoliation that might be expected.

ESTABLISHMENT AND DEVELOPMENT

An ordinary stalk of milkweed may produce several hundred seeds; and the stalks of an entire clone this number many times multiplied. The seeds with their floss are well equipped for wide distribution by wind so that every suitable site within its natural range should be well populated. This is far from being the case. In field work seedlings are rather infrequently found, and experience with seedings has not been uniformly successful. Without here going further into the bionomics of the seed it may be observed that its considerable size and lightness, even when detached from the floss, must operate to keep it from settling readily through surface material to a germination bed.

When a seedling has been successfully started a clone soon develops if conditions are good. Root extension starts in the latter part of the same year, even though new shoots do not reach the surface until the following spring. Once there is an ample foliage, surface root development becomes quite active, and plants by the second and third years from the seed, even if sown in rows, spring up indiscriminately all around and to some distance.

Numerous adventitious buds appear over all the root, the majority remaining dormant until space above or other conditions warrant their activity. The most vigorous stems arise from around the crown marking the previous year's growth. If these are lost by cutting, rub injury or disease, other buds, sometimes in excessive numbers, are called into activity. Flowering can occur in the first year but reaches its fulness only as reserves accumulate by about the third year.

The usual outcome of what has just been described is a colony of greater or less extent as soil conditions or inherent characteristics may have determined. Examination of a field shows that the stalks belong to relatively few clones, sometimes becoming intermingled, but recognizable by individuality of stature, leaf shape, colour of stalks and flowers, follicle type, etc. Each of these clones, unless root fragments were distributed by cultivation or other disturbance, had its origin from a single seed. Obviously the species is not greatly dependent for its persistence on continuous seed propagation, but has that alternative when unoccupied range is suitable and is not pre-empted by other vegetation.

AN APPLICATION OF THE FINDINGS—POD YIELD

For use in the 1944 pod collection campaign the best available advance estimates of potential production were required, and such application of the survey figures as they would bear were made. County estimates were needed for this, therefore the township data for combined field and roadside stands were brought together for the larger unit. Only those counties were included in which sampling involved travelling 10% or more of the road mileage by automobile. Before including the field stands in the combined totals, however, they were weighted by three, which was considered a safe factor to extend observations from the road to the middle of any block of land and thus represent total milkweed population. The average per mile for these counties was then multiplied by the total mileage in roads, as supplied by the Ontario Department of Highways, to give the figures in the 4th column, Table 2. Further, a rough assumption of 1 pod for each 2 stalks, and 800 pods per bushel was made for the purpose of calculation. It is appreciated that in these particulars variation can be quite wide. As merely the best figures immediately available on yield, and for comparative rather than absolute use, they are set down as worked out in Table 2.

From Table 2 it would appear that Simcoe and Renfrew are the really high producing counties. Next in order are Peterborough, Ontario, York and Norfolk. All these are counties where field stands contributed heavily to the total, and the weighting to apply the field stand results to the whole area was additionally in their favour. Counties notably low are Lincoln, Haldimand and Halton in the west, and Lennox and Addington and Frontenac in the east.

While the actual figures of pod collection in 1944 are not available at the time of writing, some indication of the reliability of these estimates may be gained from the yields of dried leaves in 1943. The counties given a high estimate above, except Norfolk, provided over one-half ton of dried leaves, while the four named for low pod yield collected one-half ton or

less. Quite extraneous reasons for the relatively low leaf collection of only one-quarter ton in Norfolk are to be found. It is obvious that many things besides actual yield enter into the ultimate collection results.

TABLE 2.—MILKWEED DENSITY AND ESTIMATE OF POD YIELD FOR SOME COUNTIES IN ONTARIO

County	Stalks per mile		Miles of road in county	Total stalks (thousands)*	Green* pod yield (bushels)
	Roadside Stands	Field Stands			
Carleton	1,665	5,850	1,298	24,900	15,600
Essex	3,000	3,760	1,176	16,800	10,500
Frontenac	360	370	1,121	1,650	1,030
Haldimand	720	870	757	1,850	1,150
Halton	700	575	573	1,900	1,180
Hastings	560	1,870	1,777	10,970	6,850
Kent	1,000	4,085	1,602	21,240	12,650
Lanark	1,600	5,200	1,216	20,900	13,000
Leeds and Grenville	760	450	1,660	7,300	4,570
Lennox and Addington	420	120	809	640	400
Lincoln	160	200	816	620	390
Middlesex	900	1,775	1,999	12,470	7,800
Norfolk	1,820	8,850	1,130	32,000	20,000
Ontario	1,161	12,760	1,381	54,400	34,000
Peel	500	3,625	724	8,240	5,150
Peterborough	1,240	17,300	1,122	59,700	37,300
Prescott and Russell	1,140	2,870	1,234	24,700	15,000
Prince Edward	370	2,000	547	3,500	2,200
Renfrew	800	17,640	1,914	102,800	64,260
Simcoe	1,470	16,340	2,369	119,600	75,750
Victoria	1,000	8,000	1,114	27,900	17,450
Wentworth	1,015	7,610	718	17,100	10,700
York	665	7,580	2,014	47,150	29,470

* Calculated as described in text.

OTHER MILKWEEDS

Swamp milkweed (*Asclepias incarnata* L.) was in essentially the same Ontario range but occupying distinctly moister habitat. It was relatively uncommon in the eastern parts, more abundant in the Peterborough district, and reached high prevalence only in the southwestern peninsula. It was especially prominent in roadside ditches and other wet land in Kent, Essex and parts of Lambton Counties. Butterflyweed (*Asclepias tuberosa* L.) was found common only in sandy areas along Lake Erie and lower Lake Huron, rare and sporadic on sand plains elsewhere, and including one such in the Ottawa district. Sullivant's milkweed (*Asclepias Sullivantii* Engelm.) has been found at a few stations about Lake St. Clair, through the efforts in the past two years largely of Dr. W. Sherwood Fox. A few other species are known by herbarium specimens to be represented in southern Ontario counties. The pods of any which are not too rare may find their way into collections of common milkweed and without serious objection to such admixture.

SUMMARY

A survey of density and distribution of the wild stands of common milkweed (*Asclepias syriaca*) in Old Ontario (including the Quebec side of the Ottawa Valley) involved 6,132 miles of travel by automobile and train. Roadside and field colonies were recorded by density grades and were then

combined to be expressed as stalks per mile of travel. Maps prepared by plotting these figures by townships provided a mosaic from which regions of high or low density are apparent. Survey technique has been detailed.

Three main concentrations of milkweed are: the Ottawa Valley mostly westward from Ottawa; the morainic belt extending through the Trent drainage system to Georgian Bay; and the southwestern peninsula bordering Lake Erie to Detroit River. Regions of light occurrence are: the Frontenac axis of Precambrian rock and borders; heavy soil plains of the ancient glacial lakes bordering the lower Great Lakes; and much of the extensive plateau between the Niagara escarpment and Lake Huron.

Factors most strongly influencing this pattern of distribution and density appear to be: soil drainage and aeration; absence of shading; and various cultural conditions. Topography has its bearing on drainage. Within wide limits precipitation is of minor importance except as, superimposed on soils, it helps to create a complexity of drainage types. On heavy lowlands plants are subjected to extremes of wetness and desiccation, while alluvium and sandy or loamy tracts remain more uniform. Soil texture otherwise is secondary to fertility and agricultural fitness. Neutral soil reaction supports milkweed better than an extreme of acidic from granitic or sandstone derivation; but limestone, at the other extreme, is commonly tolerable because leached out to leave but slight alkalinity.

Although perfectly at home in the best of farming land, milkweed finds its opportunity oftener in submarginal lands not so well utilized, or in suburban areas, on neglected waysides, or in fields reverting to sod or newly broken from sod. Otherwise, stiff sod, swampy and wooded areas chiefly restrict it. Being unpalatable to live stock it also escapes the grazing suffered by other weeds. While subject to attack by various parasites it is not seriously held in check by these.

Although a high production of plumed seeds provides for wide colonization, actual propagation is more efficiently accomplished by the fleshy creeping roots.

The survey, besides helping to clarify understanding of environmental relations, has provided some guidance for pod collection activities through advance estimates of potential yield from each district.

ACKNOWLEDGMENTS

As one phase of milkweed investigations under the general direction of Dr. H. A. Senn, Associate Botanist in the Division, the project has had his constant encouragement and help. In field work Agricultural Representatives of the Ontario Department of Agriculture have frequently been of assistance, as also Mr. William Newman in the Peterborough area, President W. Sherwood Fox of the University of Western Ontario in that part of the province, Mr. W. S. Rowe, Guelph, in western Ontario, and Major L. I. Johnson, Ottawa, in eastern Ontario. To these, and others who have been helpful, sincere thanks are extended.

REFERENCE

1. GROH, HERBERT. Notes on common milkweed. *Sci. Agr.* 23 : 625-632. 1943.

A NEW LETHAL IN SHEEP

NERVOUS INCO-ORDINATION OR PARALYSIS AT BIRTH¹

K. RASMUSSEN²

Dominion Experimental Station, Lethbridge, Alberta

[Received for publication December 29, 1944]

For a number of years sporadic cases of paralysis in new born lambs have been noticed in the sheep flock at the Dominion Experimental Station, Lethbridge, Alberta. No special significance was attached to them as they were considered to be individual abnormalities. However, in 1942 a concentration of these cases was observed in one of the four inbred lines of Canadian Corriedales in the flock, and no cases occurred in any of the other breeding groups. Consequently it appeared that there was a genetic basis for this abnormality as all the sheep were managed as one flock except during the breeding season when breeding groups were segregated. During the breeding season all sheep were handled and fed in a similar manner so it was reasonable to assume that the condition was not dependent on environmental or nutritional factors.

REVIEW OF LITERATURE

The most recent review of lethal and sublethal characters in farm animals by Lerner (1) lists only two abnormalities in sheep, namely, muscle contracture and paralysis, that indicated a possible similarity to the condition observed in the Lethbridge flock. Roberts (2) originally reported on the condition of muscle contracture in new born lambs. The main characteristic of this abnormality was that the limbs were rigidly fixed, with only a small amount of movement at the joints. Zophoniasson (3) reported on the condition of paralysis in Icelandic sheep in which the affected lambs were lame at birth and with inco-ordination in the rear quarters. The description given in his report indicated that the condition was not similar to that reported in this paper.

DESCRIPTION OF ABNORMALITY

Observation of cases occurring in 1942 first led to the belief that the condition was readily recognized but in subsequent years it has become evident that a considerable range exists in the severity of the affliction so that in some cases the condition may be overlooked. In what may be considered to be typically severe cases the lambs are unable to get to their feet without assistance and cannot stand even when placed on their feet. Another characteristic of the severe cases is that there appears to be a muscle contracture causing a concave curvature of the back when the animals are lying down and a tendency for the neck to be flexed so that the head is drawn sideways from the normal plane. Furthermore, there is usually a more or less continuous muscular movement causing a twitching and kicking of the legs.

¹Contribution from the Experimental Farms Service, Dominion Department of Agriculture, Ottawa, Canada.

²Head, Animal Husbandry Section, Dominion Experimental Station, Lethbridge, Alta.

From the severe symptoms there is a gradual diminution to the stage where the affected lambs cannot be distinguished with accuracy from lambs that may be weak at birth for other reasons. In some mild cases the lambs appear to be normal but as they develop and begin to move about it is noticed that their gait and stance are abnormal. The most noticeable feature of such cases is that the legs, particularly the hind legs, are not properly drawn under the body and this gives the lambs a spraddled appearance. Lambs affected in this manner have difficulty in walking as the legs are dragged rather than lifted in the normal manner.

The severely affected animals usually die within 48 hours of birth, mainly because of starvation brought about by their inability to stand and suckle. In 1942 one severely affected lamb was assisted for a couple of days and then improved to the point where it could get up and move around with some difficulty. For about a week it appeared to be making progress but then it began to weaken and finally died on the fourteenth day. Figures 1 and 2 (Plate 1) show this lamb in characteristic poses two days before death. It could drag itself along by using the front legs but had no power in the hind quarters.

Figures 3 and 4 show a lamb that was quite severely affected but was able to move about though it later died. These illustrations show the extreme condition of the abnormal stance of lambs affected but able to walk.

A lamb with slight symptoms is shown in Figures 5 and 6. This lamb was not observed to be abnormal until it was about a month old but then it was seen to always fall behind when the flock was being moved. Further observation showed that it had the abnormal gait that since has been found to be characteristic of the milder cases. The pictures do not show extreme abnormality but do indicate an abnormal position of the legs when the lamb is standing.

BREEDING HISTORY

Since this condition first was noted in 1942 a study has been made of the possible hereditary nature of the condition and while this study is not completed it was thought that the material might be of sufficient interest to justify its publication.

The inbred line in which the abnormality first was observed is designated as Line 4. It was set up in the fall of 1934 along with other lines in the Canadian Corriedale flock developed at this Station. All lines had the same origin and had been flock mated up to that time. The division of ewes into lines was largely on a random basis and the original sires were selected from males available in the flock. The lines have been kept intact since their inception with the exception that one line was discontinued and the ewes divided among the remaining lines. Furthermore, one of the original lines has since become so large that it has been divided into two sub-lines.



CAPTIONS

FIGURES 1 and 2 show a lamb so severely paralysed that it was unable to stand. Position of hind legs shows complete lack of control. Figures 3 and 4 show the abnormal stance of a lamb severely paralysed but able to walk. Figures 5 and 6 are of a lamb only slightly paralysed. Casual observation in a flock might not identify such a lamb.

The 1942 lambing record of Line 4, in which the abnormality appeared, is summarized in Table 1.

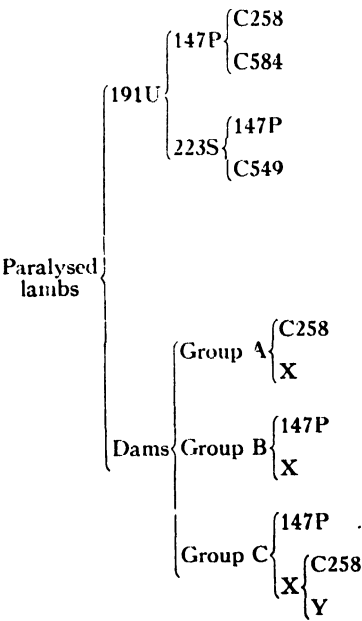
TABLE 1.—PROGENY RECORD FOR LINE 4 IN 1942

Classification of lambs	Inbred	Non-inbred
Normal	28	9
Paralysed	9	1
Dead at birth	4	0
Died the first day	0	1
Killed at birth	2	1
Total	43	12

The only data to which any significance can be attached are those classed as “normal” and “paralysed.” Lambs dead at birth may or may not have been paralysed but this could not be determined. Those killed at birth were destroyed for other reasons having no apparent bearing on the present case.

The ratio of 9 paralysed to 28 normal in the inbred group definitely points to a genetic factor of a recessive nature. The single case among the non-inbreds need cause no particular disturbance as the gene responsible may well have been in the original stock from which the line was segregated.

The relationship of the various inbred paralysed progeny is shown in the accompanying chart.



This chart shows that all the paralysed lambs were sired by the same sire (191U) and the dams of the paralysed lambs were closely related to this sire.

EXPERIMENTAL MATINGS

In order to study further the inheritance of the abnormality a special breeding group was set up in the fall of 1942. In this group all ewes that had produced paralysed lambs in Line 4 were mated back to the sire, 191U, that had produced paralysed lambs in this line. These same matings were continued in 1943 with the remaining ewes. A summary of the lambing results for these matings in 1942, 1943, and 1944 is given in Table 2.

TABLE 2.—PROGENY RECORD OF EWES THAT PRODUCED PARALYSED LAMBS WHEN MATED TO RAM 191U

Ewe	1942		1943		1944		Total 1942, 1943, 1944	Total 1943, 1944
	Sex of lamb	Class*	Sex of lamb	Class	Sex of lamb	Class		
156S	M —	P —	M M	P N	F —	N —	— —	— —
185S	M —	P —	F M	N N	M M	N N	— —	— —
223S	M M	N P	M M	P P	M M	N N	— —	— —
41T	M	P	M	P	M	N	—	—
95T	P —	P —	M ?	P P	M —	P —	— —	— —
103T	M M	P P	— —	— —	F F	N P	— —	— —
212S	F	P	—	—	—	—	—	—
Total lambs	9		9		9		27	18
Paralysed		8		6		2	16	8
Normal		1		3		7	11	10

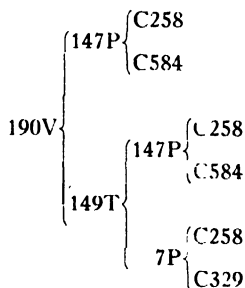
* P = paralysed.
N = normal.

Twenty-seven lambs were produced by these ewes during the three years but in view of the fact that the ewes originally were selected because they had produced defective lambs the 1942 data cannot be used in the present analysis. In 1943 and 1944, eighteen lambs were produced of which 8 were classed as defective and 10 as normal. It should be emphasized, as indicated earlier, that some mild cases of the defect may have escaped attention so the classification may not be completely accurate.

The data in Table 1 indicate that the defect is conditioned by a recessive gene and this is supported by the data in Table 2. However, the results from the special breeding group indicate that this may not be a simple case of a homozygous recessive condition. Undoubtedly there are

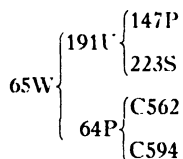
modifying genes involved and there is some evidence to show that possibly the milder form of the defect exists in individuals that are heterozygous for the causative gene. A definite decision on this cannot be made on the basis of available data.

Some supplementary evidence is available from the matings in Line 4. The ewes that did not produce paralysed progeny in this line in 1942 were continued in the line and mated that fall to ram 190V whose pedigree is as follows:



This is the same pedigree as that of 191U with the exception of the maternal section of the dam. In the 1943 progeny from this sire no paralysed lambs occurred. This would indicate either that this sire was free from the gene for the defect, or that all the heterozygous ewes had been removed from the group. This latter assumption is logically unsound and furthermore has been proven incorrect by later matings.

In 1943 a third ram, 65W, was used in Line 4. His pedigree is



On the maternal side he had no immediate relationship to the other rams, but apparently he had received the gene from his sire as he produced three paralysed progeny in the 1944 lamb crop resulting from this mating.

DISCUSSION

While the breeding experiments are incomplete and not fully critical, the data support the assumption that the condition of paralysis observed in new born lambs has a hereditary basis and is not caused by specific environmental or nutritional factors. The simplest explanation of its mode of inheritance is that it is conditioned by a recessive gene with modifiers that determine the degree of expression. It might be assumed that the more severe cases are homozygous recessive animals whereas the heterozygotes would exhibit the less severe manifestations of the condition. The observations made on new born lambs have not been sufficiently critical to provide adequate data on which to base definite conclusions in this regard. Furthermore, breeding tests would have to be conducted to verify such a hypothesis, and this has not been possible up to the present time.

PRACTICAL SIGNIFICANCE

Any abnormality that results in death of lambs is of definite practical importance. Consequently the paralytic condition described in this paper must be given serious attention wherever it may appear. It is by no means self eliminating even though all the homozygotes may die and a number of heterozygotes be eliminated through culling. It may be possible eventually to learn to detect all affected animals while they are young and thus eliminate them from the flock, but further study will be required along these lines. Until this can be determined the incidence of the characteristic can be kept at a minimum by systematic culling of all abnormal animals and by disposing of all breeding stock, that through a breeding test, have been shown to be carriers of the gene.

SUMMARY

A lethal deformity of new born lambs is described. The main characteristic of this abnormality is inco-ordination of muscular action causing the lambs to be unable to stand. Muscle contracture in the muscles of the back and neck was observed in some cases. Also in some cases a continuous involuntary muscular activity caused the legs to constantly twitch and kick.

The characteristic appeared sporadically before inbreeding was started in the flock and then it concentrated in Line 4. The evidence from the breeding history indicated that the deformity was conditioned by a recessive gene.

Further evidence from experimental matings substantiated this but also showed that apparently modifying genes were at work as various degrees of the abnormality became noticeable.

In typically severe cases, assumed to be homozygous, death ensued within 48 hours because of starvation as the lambs were unable to stand. Milder cases survived but were characterized by abnormal gait and stance.

REFERENCES

1. LERNER, I. MICHAEL. Lethal and sublethal characters in farm animals. *J. Heredity*, 35 : 219-224. 1944.
2. ROBERTS, J. A. FRASER. The inheritance of a lethal muscle contracture in the sheep. *J. Genetics*, 21 : 57-69. 1929.
3. ZOPHONIASSON, P. To Dodbringende Arvefaktorer hos de islandske Faar. *Nord. Jordbrugsforskning*, 4 : 327-330. 1930.

STUDIES ON THE OPTIMUM NUTRITION OF FLUE-CURED TOBACCO¹

E. T. McEvoy²

Experimental Farms Service, Ottawa, Ontario

[Received for publication January 25, 1945]

While the nutrition of the tobacco plant has been studied extensively in sand and water culture, very little work has been done concerning the concentrations and relative proportions of all six major nutrient elements most favourable for the development of the plant. Therefore, a series of experiments was conducted at Ottawa to determine the optimum major-element requirements of flue-cured tobacco in sand culture and the effect of the nutrient ions on the growth of the plant.

A multiple-salt system of nutrient solutions was used. The solutions were devised from the triangle of Shive (2), using the system presented by Beckenback *et al.* (1). By this method, the relative concentrations of the cations and the anions are varied separately, providing a means of studying the physiological significance of the various ions. The cations are varied in multiples of a selected increment of the total concentration due to the cations, and the anions are varied similarly, the total number of increments for cations and anions per treatment remaining the same for each series of solutions. All nutrient solutions in each series are made up to approximately the same osmotic concentration. Likewise, the pH value varies very little throughout the series. Thus, these two factors, which are important in their influence upon the growth of the plant, are held constant, or nearly so, throughout the series.

A number of ionic proportions were selected and each of the cation proportions was combined with each of the anion proportions, making a series of nutrient solutions. These were arranged into a number of sub-series, in each of which the ratio of the cations was held constant but that of the anions was varied through the full range of proportions employed. A rearrangement of the same treatments gave additional sub-series, in each of which, conversely, the ratio of the anions was held constant but the cations were varied through the full range of proportions.

All solutions throughout the experiments contained the minor elements boron, manganese, and zinc at a concentration of 0.5 p.p.m. and iron at a concentration of 3.0 p.p.m.

Tobacco plants of the flue-cured variety White Mammoth were used in this experiment. The seedlings were grown for 8 weeks in sand culture in 3-inch pots, and all were supplied with the same nutrient solution. Shive and Robbins' formula II (3) was used for the first series, but was replaced in subsequent series by solutions developed in this investigation which produced better growth. The seedlings were transplanted to 3-gallon glazed jars, holding 40 pounds of washed, ground Nepean sandstone. One

¹ Contribution from the Tobacco Division, Experimental Farms Service, Dominion Department of Agriculture, Ottawa, Ontario.
² Agricultural Scientist.

plant was grown in each jar and the nutrient solution was supplied by the constant flow method from glass jars and capillary tubing, 1 litre per day being supplied to each plant.

The plants were harvested when mature, 2 weeks after topping. The stalks were cut off at the crown, the total fresh weights were determined and the stalks and leaves were separated for the determination of green weights and dry weights. The fractions were thoroughly mixed and aliquots were weighted for the various determinations. The samples were dried at a temperature of 70 to 80° C.

An analysis of variance, based on the total fresh weight data of the plants, was performed for each series. While a summary of this work is not presented, the difference between any two fresh weight means necessary for significance at the 5% level is appended to each table.

RESULTS

Series I

In the first series, the plants were grown in 16 different nutrient solutions used by Beckenbach *et al* (1), each solution being made up to a total osmotic concentration of 0.5 atmosphere. The following chemically pure salts were used to balance the ionic ratios: KH_2PO_4 , $\text{CaH}_4(\text{PO}_4)_2$, $\text{MgH}_4(\text{PO}_4)_2$, KNO_3 , $\text{Ca}(\text{NO}_3)_2$, $\text{Mg}(\text{NO}_3)_2$, K_2SO_4 , CaSO_4 , and MgSO_4 . The 16 treatments were divided into 8 sub-series. Sub-series 1 to 4 are characterized by fixed cation proportions and sub-series 5 to 8 are characterized by fixed anion proportions, each having variations in the relative proportions of the ions of opposite charge.

The seedlings were planted on October 21, 1939, and the plants were harvested on January 2, 1940. Three replications of each treatment were used.

The ionic proportions used and a summary of the results are presented in Table 1. The arrangement of treatments in sub-series 1 to 4 provides for a study of the influence on growth of the different anion proportions for each of the four fixed cation proportions. Considering the fresh weight yield in grams as the criterion of growth, greater growth was produced by treatments high in NO_3 and low in PO_4 and SO_4 than by any other treatment for each of the four fixed cation proportions. The 3-4-3 anion ratio ranked second in each case; however, in sub-series 4, it was not significantly different from the 8-1-1 anion ratio. The differences between the high SO_4 and the high PO_4 treatments were not statistically significant, except in sub-series 4 in which high PO_4 produced the greater yield. Over the range of anion variations employed, the greatest variation in yield was manifested when Ca was high, next greatest when the cation distribution was 3-4-3, and least when Mg was high.

In sub-series 5 to 8 of Table 1, the arrangement of treatments provides for a similar study of the data on the cation ratios. While the fresh weight yield associated with the cation ratio 3-4-3 ranked first in all cases, the increase in yield shown by this ratio over each of treatments 6 to 10 in sub-series 5, 16 in sub-series 6, and 5 in sub-series 7 was not statistically significant. When NO_3 was high, high yield was associated with intermediate Ca and high Ca in that order; when PO_4 was high, high yield was

TABLE 1.—YIELD DATA FOR SERIES I, ARRANGED IN SUB-SERIES 1-4 FOR COMPARISON OF ANION EFFECT UPON GROWTH AND IN SUB-SERIES 5-8 FOR COMPARISON OF CATION EFFECT UPON GROWTH

Sub-series No.	Treatment No.	Cation proportions			Anion proportions			Mean fresh weight per plant	Mean dry weight per plant	Per cent dry weight			Water per gram dry weight	
		Ca	Mg	K	NO ₃	SO ₄	PO ₄			Per plant	Stalks	Leaves	Stalks	Leaves
								gm.	gm.	%	%	%	gm.	gm.
1	1	3	4	3	3	4	3	128 ± 4.2*	10.2	7.9	7.2	8.3	12.9	11.1
	2	3	4	3	1	1	8	94 ± 5.2	10.4	11.0	10.7	11.2	8.4	8.0
	3	3	4	3	8	1	1	181 ± 23.3	16.9	9.4	10.0	9.1	9.0	10.0
	4	3	4	3	1	8	1	95 ± 10.7	8.6	9.1	8.8	9.2	9.0	9.9
2	5	8	1	1	8	1	1	179 ± 2.0	20.7	11.5	11.0	11.8	8.1	8.5
	6	8	1	1	3	4	3	118 ± 7.0	12.7	10.7	11.2	10.5	7.9	8.5
	7	8	1	1	1	8	1	72 ± 3.2	8.4	11.7	11.8	11.6	7.5	7.6
	8	8	1	1	1	1	8	71 ± 3.0	8.2	11.7	11.2	11.9	7.9	7.4
3	9	1	1	8	1	1	8	74 ± 3.7	7.2	9.6	11.8	10.3	11.1	8.7
	10	1	1	8	3	4	3	122 ± 7.7	12.2	9.9	12.0	9.0	7.3	10.1
	11	1	1	8	8	1	1	143 ± 8.3	12.6	8.9	10.7	8.2	8.3	11.2
	12	1	1	8	1	8	1	77 ± 14.5	8.6	11.2	11.7	10.9	7.5	8.2
4	13	1	8	1	1	8	1	69 ± 10.5	7.6	11.1	10.4	9.8	6.1	9.2
	14	1	8	1	3	4	3	101 ± 16.0	12.5	12.4	14.0	9.4	6.1	9.7
	15	1	8	1	8	1	1	109 ± 15.2	12.5	11.5	12.8	11.0	6.8	8.1
	16	1	8	1	1	1	8	86 ± 5.3	8.1	9.1	11.8	8.2	7.5	11.2
5	1	3	4	3	3	4	3	128 ± 4.2	10.2	7.9	7.2	8.3	12.9	11.1
	6	8	1	1	3	4	3	118 ± 7.0	12.7	10.7	11.2	10.5	7.9	8.5
	10	1	1	8	3	4	3	122 ± 7.7	12.2	9.9	12.0	9.0	7.3	10.1
	14	1	8	1	3	4	3	101 ± 16.0	12.5	12.4	14.0	9.4	6.1	9.7
6	2	3	4	3	1	1	8	94 ± 5.2	10.4	11.0	10.7	11.2	8.4	8.0
	8	8	1	1	1	1	8	71 ± 3.0	8.2	11.7	11.2	11.9	7.9	7.4
	9	1	1	8	1	1	8	74 ± 3.7	7.2	9.6	11.8	10.3	11.1	8.7
	16	1	8	1	1	1	8	86 ± 5.3	8.1	9.1	11.8	8.2	7.5	11.2
7	3	3	4	3	8	1	1	181 ± 23.3	16.9	9.4	10.0	9.1	9.0	10.0
	5	8	1	1	8	1	1	179 ± 2.0	20.7	11.5	11.0	11.8	8.1	8.5
	11	1	1	8	8	1	1	143 ± 8.3	12.6	8.9	10.7	8.2	8.3	11.2
	15	1	8	1	8	1	1	109 ± 15.2	12.5	11.5	12.8	11.0	6.8	8.1
8	4	3	4	3	1	8	1	95 ± 10.7	8.6	9.1	8.8	9.2	9.0	9.9
	7	8	1	1	1	8	1	72 ± 3.2	8.4	11.7	11.8	11.6	7.5	7.6
	12	1	1	8	1	8	1	77 ± 14.5	8.6	11.2	11.7	10.9	7.5	8.2
	13	1	8	1	1	8	1	69 ± 10.5	7.6	11.1	10.4	9.8	6.1	9.2

* Difference between means necessary for significance at the 5% level = 11.8.

associated with intermediate Mg and high Mg; and when SO₄ was high, high yield was associated with intermediate K and high K. However, in the last case the difference did not reach the level of significance. The 1-8-1 cation ratio, in which Mg was at its maximum concentration, gave the lowest yield in each case, except sub-series 6, and resulted in necrotic areas on the leaves, the severity of the disorder being reduced considerably when the anion distribution was high in PO₄ and low in NO₃ and SO₄. It is clearly indicated that higher concentrations of Ca and K than of Mg are required to produce good growth. Variations in the cation proportions

resulted in greatest variation in yield when the anion ratio was high in NO_3 and in least variation in yield when the NO_3 concentration was low and that of either SO_4 or PO_4 was high.

The dry weight data show that high nitrate in the nutrient solution resulted in a low percentage of dry weight in the leaf. In sub-series 1, 2, and 3, the number of grams of water per gram dry matter in the leaf tissue was greater when the solution was high in NO_3 than when either PO_4 or SO_4 was high. Only in sub-series 4 in which toxicity of Mg was manifested were the data at variance with the general results.

Solutions with a high K concentration produced plants which were consistently higher in water content of the leaf fraction than did solutions with a high Ca concentration. In contrast, solutions high in Ca all produced leaf tissue with a higher proportion of dry matter than did any other solution. Comparisons in the stalk fractions, however, were not consistent in this respect. Also, the data from high Mg were quite irregular and did not reveal any definite influence of this ion on the relative proportions of water and dry matter in the tissue.

While only a small number of the possible solutions were tested in this series, sufficient information was obtained on the importance of the relative ionic concentrations to provide a bases for an extension of the work.

Series II

Using the same 9-salt system as in series I, 16 nutrient solutions were devised. Each ion was used at three concentrations, corresponding to multiples of the one-fourteenth increment of the total concentration. The amounts of Ca and NO_3 were varied within narrow limits around the concentrations of these ions which produced best growth in series I. Mg and SO_4 were used at comparatively low concentrations since growth was depressed in series I when Mg was high and, in less degree, when the amount of SO_4 was high as compared with PO_4 (sub-series 4). K and PO_4 were used at intermediate levels. The ionic ratios used, as given in Table 2, resulted in an increase in the total supply of ions in each solution as compared to that in series I; therefore, the osmotic concentration of each solution was increased to 0.7 atmosphere.

The seedlings were planted on March 1, 1940, and the plants were harvested on May 21, 1940, three replications of each treatment being used.

The yield data for this series are summarized in Table 2. The arrangement of treatments in sub-series 1 to 4 allows for a study of the comparative effect of the anion proportions and in sub-series 5 to 8 for a similar study of the cations. It is evident that the 9-1-4 anion ratio gave a yield which was significantly higher than that of any other treatment in sub-series 1 and 3, but was not significantly different from those of the 8-2-4 ratio in sub-series 2 and the 8-2-4 and 8-4-2 ratios in sub-series 4. The 6-3-5 ratio ranked last in each case, the difference between high and low nitrate being highly significant at all four cation proportions. The 8-2-4 anion ratio ranked higher than the 8-4-2 ratio in sub-series 1 and 2, while no significance can be assigned to the differences between these two treatments in the other cases. Such comparisons show that high NO_3 is associated with

high green weight; but, when used as 9 parts of the total anion concentration, the supply of this ion is sometimes in excess of that required for maximum growth (sub-series 2 and 4). However, this level of NO_3 is not above the optimum concentration as it did not reduce yield significantly in any instance. PO_4 is required at a higher level than is SO_4 , a supply of 1 or 2 relative parts of the latter being adequate for good growth. It is not evident whether the decrease in yield when the amount of SO_4 was increased from 2 to 4 relative parts (sub-series 1 and 2), was caused by

TABLE 2.—YIELD DATA FOR SERIES II, ARRANGED IN SUB-SERIES 1-4 FOR COMPARISON OF ANION EFFECT UPON GROWTH AND IN SUB-SERIES 5-8 FOR COMPARISON OF CATION EFFECT UPON GROWTH

Sub-series No.	Treatment No.	Cation proportions			Anion proportions			Mean fresh weight per plant	Mean dry weight per plant	Per cent dry weight			Water per gram dry weight	
		Ca	Mg	K	NO_3	SO_4	PO_4			Per plant	Stalks	Leaves	Stalks	Leaves
								gm.	gm.	%	%	%	gm.	gm.
1	1	6	3	5	6	3	5	765 \pm 32.5*	109.1	14.4	14.1	14.6	6.1	5.9
	2	6	3	5	8	4	2	772 \pm 17.8	102.0	13.2	14.6	12.0	5.9	7.3
	3	6	3	5	8	2	4	862 \pm 31.6	103.8	12.0	14.1	11.1	6.1	8.0
	4	6	3	5	9	1	4	916 \pm 7.5	101.4	11.1	13.0	10.1	6.7	8.9
2	5	8	4	2	8	4	2	865 \pm 36.6	109.9	12.7	13.7	14.6	6.3	5.8
	6	8	4	2	8	2	4	908 \pm 33.9	133.0	14.6	14.5	14.7	5.9	5.8
	7	8	4	2	9	1	4	918 \pm 23.0	133.6	14.6	14.5	14.6	5.9	5.9
	8	8	4	2	6	3	5	823 \pm 31.5	123.1	15.0	14.9	15.0	5.7	5.7
3	9	8	2	4	8	2	4	920 \pm 40.7	118.0	12.8	13.9	12.2	6.2	7.2
	10	8	2	4	8	4	2	877 \pm 22.7	124.9	14.2	13.2	14.9	6.6	5.7
	11	8	2	4	9	1	4	1001 \pm 2.1	134.9	13.5	13.3	13.5	6.5	6.4
	12	8	2	4	6	3	5	855 \pm 4.6	117.9	13.8	14.1	13.6	5.1	5.4
4	13	9	1	4	9	1	4	807 \pm 8.2	131.7	14.5	13.8	14.9	6.3	5.8
	14	9	1	4	8	2	4	912 \pm 9.7	147.5	16.2	15.4	16.4	5.5	5.1
	15	9	1	4	8	4	2	928 \pm 23.9	134.9	14.5	14.6	14.5	5.9	5.9
	16	9	1	4	6	3	5	800 \pm 23.9	130.4	16.3	15.3	17.1	5.5	4.9
5	1	6	3	5	6	3	5	765 \pm 32.5	109.1	14.4	14.1	14.6	6.1	5.9
	8	8	4	2	6	3	5	823 \pm 31.5	123.1	15.0	14.9	15.0	5.7	5.7
	12	8	2	4	6	3	5	855 \pm 4.6	117.9	13.8	14.1	13.6	5.1	5.4
	16	9	1	4	6	3	5	800 \pm 23.9	130.4	16.3	15.3	17.1	5.5	4.9
6	2	6	3	5	8	4	2	772 \pm 17.8	102.0	13.2	14.6	12.0	5.9	7.3
	5	8	4	2	8	4	2	865 \pm 36.6	109.9	12.7	13.7	14.6	6.3	5.8
	10	8	2	4	8	4	2	877 \pm 22.7	124.9	14.2	13.2	14.9	6.6	5.7
	15	9	1	4	8	4	2	928 \pm 23.9	134.9	14.5	14.6	14.5	5.9	5.9
7	3	6	3	5	8	2	4	862 \pm 31.6	103.8	12.0	14.1	11.1	6.1	8.0
	6	8	4	2	8	2	4	908 \pm 33.9	133.0	14.6	14.5	14.7	5.9	5.8
	9	8	2	4	8	2	4	920 \pm 40.7	118.0	12.8	13.9	12.2	6.2	7.2
	14	9	1	4	8	2	4	912 \pm 9.7	147.5	16.2	15.4	16.4	5.5	5.1
8	4	6	3	5	9	1	4	916 \pm 7.5	101.4	11.1	13.0	10.1	6.7	8.9
	7	8	4	2	9	1	4	918 \pm 23.0	133.6	14.6	14.5	14.6	5.9	5.9
	11	8	2	4	9	1	4	1001 \pm 2.1	134.9	13.5	13.3	13.6	6.5	6.4
	13	9	1	4	9	1	4	907 \pm 8.2	131.7	14.5	13.8	14.9	6.3	5.8

* Difference between means necessary for significance at the 5% level = 45.7

the increase in SO_4 or the decrease in PO_4 since, in accordance with the design of the experiment, as the concentration of SO_4 is increased the concentration of PO_4 is proportionately decreased. On the other hand, definite evidence that SO_4 was not toxic when used at its maximum value in this series is presented in sub-series 3 and 4. Here, the difference in yield between the anion ratios 8-2-4 and 8-4-2 was not statistically significant in either case. Thus, it is evident that the plant has a wide range of tolerance of SO_4 , and a supply of this ion in the substrate ranging from 1 to 4 relative parts is favourable to growth.

A study of the data on the cations reveals that no individual cation ratio shows definite superiority throughout the series. However, it is evident that the yield produced by the 6-3-5 cation distribution was significantly lower than that of any other treatment in all sub-series except 8. In each sub-series, the highest yield was produced when 8 or 9 parts of the total cation concentration were supplied as Ca and 1 or 2 parts as Mg; however, it is not conclusive that the latter ion was toxic at any concentration used in this series. It is indicated that K is required at a relatively high concentration as yet not determined precisely.

As in Series I, high NO_3 and high K supply were each associated with high moisture content in the leaf tissue and high Ca supply was associated with high dry weight in the leaf tissue.

These data show that optimal growth can be produced when 1 to 4 parts of the anion concentration are supplied as SO_4 and 1 to 2 parts of the cation concentration as Mg. However, the most favourable concentration of each of these ions seems to be 2 parts since this amount is well above the deficiency level and any increase in the amount of either ion would necessitate a corresponding decrease in the amount of another ion of similar charge. The need of further investigation to establish the most favourable concentration of each of the other nutrient ions is indicated.

Series III

In this series, the total osmotic concentration of each nutrient solution was increased to 0.75 atmosphere. The ionic concentrations were adjusted in increments corresponding to multiples of the one-fifteenth increment of the total concentration of the anions and the cations respectively. The concentration of each of Mg and SO_4 was held constant at the 2-part level throughout the experiment and each of the other four major ions was used at the following levels: 6.5, and 8 parts. Nine solutions were devised as shown in Table 3, the ionic proportions employed being such that they could be made from 5 salts, namely KH_2PO_4 , $\text{Ca}(\text{NO}_3)_2$, MgSO_4 , $\text{CaH}_4(\text{PO}_4)_2$, and KNO_3 . Six replications of each treatment were used. The seedlings were planted on October 2, 1940, and the plants were harvested on January 14, 1941.

The results of this series are given in Table 3. The data on the anions (sub-series 1 to 3) show that the yield produced by the treatment high in NO_3 was significantly higher than that of any other treatment at all cation proportions. No significance can be ascribed to the differences in yield between the other anion proportions except in sub-series 3 in which the 6.5-2-6.5 ratio ranked second. These results affirm the previous finding

TABLE 3.—YIELD DATA FOR SERIES III, ARRANGED IN SUB-SERIES 1-3 FOR COMPARISON OF ANION EFFECT UPON GROWTH AND IN SUB-SERIES 4-6 FOR COMPARISON OF CATION EFFECT UPON GROWTH

Sub-series No.	Treatment No.	Cation proportions			Anion proportions			Mean fresh weight per plant gm. *	Mean dry weight per plant gm.	Per cent dry weight				Water per gram dry weight			
		Ca		Mg	K	No ₃	SO ₄			PO ₄	Per plant %	Stalks %	Top leaves %	Bottom leaves %	Stalks gm.	Top leaves gm.	Bottom leaves gm.
1	1	5		2	8	5	2	8	924 ± 35.7	93.9	10.2	14.8	10.0	9.4	5.7	10.0	9.0
	2	5		2	8	6.5	2	6.5	995 ± 62.3	97.3	9.8	10.8	10.1	9.2	8.7	8.8	9.8
	3	5		2	8	8	2	5	1157 ± 86.9	113.3	9.8	12.0	10.0	7.4	7.3	10.0	12.5
2	4	6.5		2	6.5	5	2	8	918 ± 50.4	115.6	11.8	15.2	13.0	7.6	5.5	6.6	12.1
	5	6.5		2	6.5	6.5	2	6.5	984 ± 27.3	141.3	14.4	15.0	13.0	14.6	5.6	6.6	5.7
	6	6.5		2	6.5	8	2	5	1097 ± 31.9	129.3	11.8	13.0	14.4	8.2	6.6	5.9	11.1
3	7	8		2	5	5	2	8	937 ± 53.2	105.0	10.6	12.0	12.2	9.6	7.3	7.2	9.4
	8	8		2	5	6.5	2	6.5	1037 ± 52.8	127.1	12.3	14.0	12.8	10.0	6.1	6.8	9.0
	9	8		2	5	8	2	5	1150 ± 102.5	132.0	11.5	13.4	11.8	6.2	6.5	7.4	15.1
4	1	5		2	8	5	2	8	924 ± 35.7	93.9	10.2	14.8	10.0	9.4	5.7	10.0	9.0
	4	6.5		2	6.5	5	2	8	918 ± 50.4	115.6	11.8	15.2	13.0	7.6	5.5	6.6	12.1
	7	8		2	5	5	2	8	937 ± 53.2	105.0	10.6	12.0	12.2	9.6	7.3	7.2	9.4
5	2	5		2	8	6.5	2	6.5	995 ± 62.3	97.3	9.8	10.8	10.1	9.2	8.7	8.8	9.8
	5	6.5		2	6.5	6.5	2	6.5	984 ± 27.3	141.3	14.4	15.0	13.0	14.6	5.6	6.6	5.7
	8	3		2	5	6.5	2	6.5	1037 ± 52.8	127.1	12.3	14.0	12.8	10.0	6.1	6.8	9.0
6	3	5		2	8	8	2	5	1157 ± 86.9	113.3	9.8	12.0	10.0	7.4	7.3	10.0	12.5
	6	6.5		2	6.5	8	2	5	1097 ± 31.9	129.3	11.8	13.0	14.4	8.2	6.6	5.9	11.1
	9	8		2	5	8	2	5	1150 ± 102.5	132.0	11.5	13.4	11.8	6.2	6.5	7.4	15.1

that NO_3 is required at a high concentration and indicate that an amount of PO_4 higher than 5 relative parts of the anion concentration is in excess of the requirement of the plant for maximum growth.

The differences in yield associated with variations in the cation proportions (sub-series 4 to 6) are not significant at any of the three anion proportions. This shows that the variations in the cation proportions employed in this series do not result in a significant variation in the yield provided the positively charged ions are at an optimum level. Therefore, a concentration of 5 to 8 parts of each of Ca and K is adequate for best growth.

The variations in ionic concentrations in this series were not sufficiently great to provide a basis for the study of the influence of each ion on the dry weight percentage of the tissue.

GENERAL DISCUSSION

It is evident that NO_3 is the anion which has the greatest influence over growth under the conditions of these experiments and that this influence is correlated with the relative cation levels. An increase in the mean fresh weight deviation indicates an increase in the importance of the cation ratio. In series I, the mean fresh weight deviation in sub-series 5, 6, and 7 was 8, 8.8 and 27.2 grams respectively. A comparison of these results shows that the efficient utilization by the plant of high NO_3 supply is greatly influenced by the relative cation supply. Thus, at low NO_3 levels (sub-series 5 and 6) the influence of variations in the cation distribution was slight and the yield was affected very little; but, at the highest NO_3 level (sub-series 7), the effectiveness of this ion in producing high yield was conditioned to a greater degree by the relative cation concentrations. Beckenback *et al.* (1) reported similarly for corn.

The PO_4 ranks second in importance among the anions and the SO_4 third. There was no indication of a deficiency of SO_4 at the lowest level and the evidence is not conclusive that this ion was toxic at any of the concentrations tested. The depression of growth in series II when SO_4 was used at a higher concentration than that of PO_4 may be attributable to a decrease in the supply of PO_4 , rather than to toxicity of SO_4 since evidence of toxicity of the latter when used at the higher levels in series I was lacking in all cases except sub-series 4. Therefore, the optimum range of SO_4 is quite wide.

Of the cations, it is shown that the solution required for maximum growth contains 5 to 8 relative parts of each of Ca and K, the combined concentration of these two ions being 13 parts out of a total of 15 relative parts of the cation concentration. The remaining 2 parts are supplied as Mg. The maximum concentration of Mg in conjunction with low Ca and K resulted in a reduction in yield and in the appearance of necrotic areas on the leaves. This necrosis was reduced in severity when the anion ratio was high in PO_4 and low in NO_3 and SO_4 .

An examination of the data leads to the conclusion that no exact ionic ratio is essential for optimum nutrition. The plant's power of adaptation seems to enable it to respond favourably to considerable variations in the concentrations of nutrient ions. Good growth was produced over a wide range of ionic ratios, provided the total supply of essential elements

was adequate. It is clearly indicated that, while there is no specific requirement of each ion for optimum nutrition, there is a definite range of concentrations of each ion for optimum requirements.

Based on the results of these investigations, the concentration range of each of the 6 major nutrient ions for optimum nutrition of White Mammoth is given in Section A of Table 4 in terms of the relative parts of the concentration of the ions as used in this work. The data in Section B of Table 4 give the concentration of the nutrient element contained in each ion per million parts of the nutrient solution at the ionic levels given in Section A.

TABLE 4

A—THE CONCENTRATION RANGE OF THE SIX MAJOR NUTRIENT IONS FOR OPTIMUM NUTRITION OF WHITE MAMMOTH		B—THE CONCENTRATION IN P.P.M. OF THE NUTRIENT ELEMENT CONTAINED IN EACH MAJOR ION AT THE IONIC LEVELS GIVEN IN TABLE 4A	
Nutrient ion	Relative parts of concentration of ions	Nutrient element	P.p.m. of nutrient element
Ca	5 - 8	Ca	150 - 240
Mg	1 - 2	Mg	34 - 68
K	5 - 8	K	200 - 320
NO ₃	8 - 9	N	168 - 189
SO ₄	1 - 4	S	45 - 180
PO ₄	4 - 5	P	124 - 155

Further physiological effects of the individual ions are revealed by the dry weight data. It is shown that the concentration of NO₃ in the nutrient medium is the primary factor in determining the proportion of dry weight. An increase in the NO₃ supply results in an increase in the proportion of water in the leaf tissue, while the relative proportions of SO₄ and PO₄ do not seem to have any definite influence on the moisture content of the tissue. Of the cations, a high level of K in the nutrient solution produced plants with a relatively high percentage of water in the leaf tissue, while a high level of Ca in the solution resulted in a high percentage of dry matter in this tissue.

SUMMARY

A study was made of the effect of the six major nutrient ions on the growth of flue-cured tobacco in artificial culture and an optimum nutrient solution was developed for the variety White Mammoth. It was shown that no exact ionic ratio in the nutrient medium is required for maximum growth, but the optimum concentration range of each nutrient ion was determined.

The highest correlation between the nutrient supply and the growth of the plant was observed for NO₃ between the limits of one and nine, out of a total of 15 relative parts of the anion concentration. NO₃ was followed in order of influence of the anions on growth by PO₄ and SO₄. The plant manifested a wide range of tolerance of SO₄.

At increasingly high concentrations of NO_3 in the nutrient solution, the effectiveness of this ion in producing high yield was conditioned in increasing degree by the relative proportions of Ca, Mg, and K in the nutrient solution. At high NO_3 levels, greatest growth was produced when Ca and K were each supplied at a concentration of 5 to 8 parts out of a total of 15 relative parts of the cation concentration, the combined concentration of the two ions being 13 parts. The remaining 2 parts were supplied as Mg.

An increase in the nutrient supply of each of NO_3 and K was associated with an increase in the percentage of water in the leaf tissue while an increase in the supply of Ca was associated with an increase in the percentage of dry material in the leaf tissue. No relationship was observed between the supply of PO_4 , SO_4 , and Mg and the relative proportions of water and dry matter in the tissue.

REFERENCES

1. BECKENBACH, J. R., C. H. WADLEIGH and J. W. SHIVE. Nutrition studies with corn: I. A statistical interpretation of the nutrient ion effect upon growth in artificial culture. *Soil Sci.* 41 : 469-489. 1936.
2. SHIVE, J. W. A study of the physiological balance in nutrient media. *Johns Hopkins Univ. Bot. Contrib.* 46. 1915.
3. SHIVE, J. W. and W. R. ROBBINS. Methods of growing plants in solutions and sand culture. *N.J. Agr. Exp. St. Bul.* 636. 1938.

A NOTE ON THE PRODUCTION OF VITAMIN C BY SPROUTING SEEDS¹

L. P. V. JOHNSON², G. A. YOUNG,³ AND J. B. MARSHALL²

National Research Laboratories, Ottawa

The antiscorbutic value of germinated seeds has been known since the time of Captain Cook, and was investigated in Norway prior to the last war (5). After the Mesopotamian campaign of 1915-16 British workers directed attention to the possibility of utilizing this property as a source of accessory dietary factors for troops separated from supplies of fresh food and for the relief of famine stricken areas (1). Advances since 1918 in the knowledge of the chemistry of vitamins have made it possible to investigate more comprehensively methods for the production and preparation of an antiscorbutic material from sprouted seeds. In this note the results are given of a survey to determine the suitability, for this purpose, of seeds readily available in Canada, as well as some others less commonly known.

Legumes have been considered more prolific producers of ascorbic acid than cereals (5) and there is evidence of physiological differences between crop varieties as well. Bonner and Bonner (3) showed that pea varieties could be grouped according to their response to the presence of ascorbic acid in the media in which excised embryos were cultured. This response was related inversely to the concentration of ascorbic acid initially present in the embryos. The presence of ascorbic acid in actively growing tissues, i.e. hypocotyl, and later in chlorophyll bearing tissues has been demonstrated by Reid (4).

MATERIALS

The material examined included varieties of the following crops: common and garden peas, *Pisum sativum*; common bean, *Phaseolus vulgaris*; green gram bean⁴, *P. aureus*; lima bean, *P. lunatus*; English broad bean, *Vicia fabia*; soy bean, *Glycine soja*; spring wheat, *Triticum sativum*; hull-less oats, *Avena nuda*; corn, *Zea mays*, v. *saccharata*; okra, *Hibiscus esculentus*. A complete list including variety names is given in Table 1. The seed used in each case was of good quality, having been graded previously for seed purposes. This initial quality is of importance as sound viable seed gives some assurance of optimum performance in the sprouting tests. Broken and disease infected seeds tend to decompose readily and this may render the odour of an entire batch of seed offensive.

METHODS

Preliminary tests of the above material were made by germinating the seeds in petri dishes at 22.2° C. (72° F.) after soaking for 24 hours in tap

¹ Contribution from the Division of Applied Biology, National Research Laboratories. Issued as Paper No. 1247.

Work carried out for the Associate Committee on Army Medical Research, National Research Council Ottawa, and the Research Division, D.G.M.S., National Defence Headquarters, Ottawa.

² Biologist.

³ Laboratory Steward.

⁴ This species is closely related to the mung or black gram bean, *Phaseolus mungo* (2).

TABLE 1.—VARIETIES USED IN PRELIMINARY TESTS OF ASCORBIC ACID PRODUCTION

<i>Common pea, Pisum sativum</i> Field varieties Arthur Chancellor Dashaway Early Blue (Ottawa No. 21) Early Britain Golden Vine (1)* Mackay (Ottawa No. 25) (1) New Canadian Beauty Potter Prussian Blue (1) Garden varieties Dwarf Gray Sugar Little Marvel Prince of Wales (1) Thomas Laxton <i>Soy bean, Glycine soja</i> Blackeye (1) (2) Mandarin <i>Okra, Hibiscus esculentus</i> White Velvet (3)	<i>Common bean, Phaseolus vulgaris</i> Common white (1) Marrow fat (1) Red Kidney (1) <i>Lima Bean, P. lunatus</i> Burpee Bush Lima (1) Henderson Bush Lima (1) <i>Green Gram bean, P. aureus</i> Chinese Salad <i>English Broad bean, Vicia fabia</i> Broad Windsor <i>Spring wheat, Triticum sativum</i> Marquis Regent (2) Thatcher (2) <i>Hull-less oats, Avena nuda</i> Laurel <i>Corn (maize), Zea mays v. saccharata</i> Golden Bantam
--	---

* Reasons for elimination from further tests:

- (1) Soured during germination.
- (2) Low vitamin C production
- (3) Poor germination.

water. Ascorbic acid determinations were made at daily intervals, commencing when the sprouts first appeared and continuing until the assay values began to decline. A number of varieties were eliminated on this basis.

The material thus selected was tested at three temperatures, 15.6°, 22.2°, and 28.9° C. (60°, 72°, and 84° F.) and by two methods of germination. In one, the seeds were soaked in trays for 24 hours, drained, spread to a depth of $\frac{3}{4}$ inch and flushed with water at the temperature required. The other method was similar to that recommended for use by the Australian Forces (6); seed was placed in loose cheese cloth bags, soaked 24 hours and thereafter dipped 4 times daily in water held at the germination temperatures.

Vitamin C assays were made on samples of the entire sprouted material. No attempt was made to separate the sprouts from the seeds and seed coats. Reduced ascorbic acid was determined by the dye titration method, 2% metaphosphoric acid being used to extract the material in a *Waring Blender*. Moisture determinations were made on the material as well, in order to allow for the diluting effect of the tissue water. The results are expressed as mg. ascorbic acid per 100 gm. of sprouted material.

RESULTS

In the preliminary tests 14 of the 31 varieties listed in Table 1 were eliminated for various reasons. A number of the pea and bean varieties

showed a pronounced tendency to become sour and offensive when germinated in this manner. Two of the wheat varieties were dropped because of low vitamin C production, and tests of okra were discontinued because of poor germination of the seed used.

For convenience and expediency the bag method of germination was used for most of the tests, and the data presented are based on this method. The two methods did not differ appreciably. Considerable care was required with the trays that were used, to avoid souring as a result of impeded drainage and lack of aeration. Trays with perforated bottoms would have been much more satisfactory.

Data showing the effects of temperature on vitamin C production and the condition of the sprouted material are given in Table 2. Rapid souring or spoilage of all the material except the Chinese Salad bean resulted at 28.9° C. Of the other temperatures the lower (15.6° C.) was more favourable for the legumes and the higher (22.2° C.) for the cereals.

TABLE 2.—EFFECT OF TEMPERATURE ON THE VITAMIN C PRODUCTION AND GROWTH OF SEEDS OF SELECTED VARIETIES GERMINATED IN BAGS

Crop	Variety	Temp. °C.	No. days for maximum production	*Growth	Condition of material	Mg./100 gm. of material		Per- centage moist- ure
						Wet	Dry	
Bean	Chinese Salad	15.6	3	Good	Fresh	23	89	74
	English Broad Windsor		7	Very good	Slightly sour	33	122	73
	Mandarin Soy		4	Fair	Fresh	4	13	68
Corn	Golden Bantam	22.2	7	Good	Sour	7	20	63
Oats	Laurel		6	Very good	Fresh	8	30	75
Pea	Arthur		5	Very good	Fresh	17	61	67
Wheat	Marquis		5	Very good	Fresh	4	16	75
Bean	Chinese Salad	22.2	2	Very good	Fresh	21	65	68
	English Broad Windsor		4	Good	Sour	23	73	69
	Mandarin Soy		3	Poor	Sour	2	3	32
Corn	Golden Bantam	28.9	4	Very good	Fresh	10	30	65
Oats	Laurel		6	Very good	Slightly sour	11	19	43
Pea	Arthur		3	Fair	Fresh	3	7	64
Wheat	Marquis		4	Very good	Fresh	5	13	65
Bean	Chinese Salad	28.9	2	Fair	Fresh	18	64	73
	English Broad Windsor		2	Poor	Sour	—	—	—
	Mandarin Soy		2	Poor	Sour	—	—	—
Corn	Golden Bantam	28.9	2	Poor	Sour	—	—	—
Oats	Laurel		2	Poor	Sour	1	1	43
Pea	Arthur		2	Poor	Sour	—	—	—
Wheat	Marquis		2	Fair	Slightly sour	1	2	47

* Growth poor, less than 50% germination; fair, less than 75% germination; good, less than 95% germination; very good, 95 to 100% germination.

A comparison of 12 varieties of peas sprouted in bags at 15.6° C. is given in Table 3. Early Blue (Ottawa No. 21), O.A.C. No. 181 and Arthur

TABLE 3.—VITAMIN C PRODUCTION AND GROWTH IN FIELD AND GARDEN PEAS, SPROUTED IN BAGS AT 15.6° C.

Variety	No. days for maximum production	Growth	Mg./100 gm. of material wet basis
Arthur	5	Good	17
Chancellor	4	Poor	8
Dwarf Grey Sugar	4	Fair	11
Dashaway	4	Fair	12
Early Blue, Ottawa No. 21	5	Good	20
Early Britain	4	Fair	11
Little Marvel	4	Fair	14
New Canadian Beauty	4	Poor	10
O.A.C. No. 181	5	Good	18
Potter	4	Good	13
Thomas Laxton	4	Good	10
White Wonder	4	Fair	9

took 5 days to reach their maximum vitamin C production (17 to 20 mg. per 100 g.), while the other varieties began to decline at 4 days, after having reached a maximum of 8 to 14 mg. per 100 g.

In Figure 1 the daily increases in the ascorbic acid content of 100 gm. of sprouting material are shown for selected seeds, germinated in bags at 15.6° C. The Chinese Salad bean reached a maximum in 3 days while the Broad Windsor bean took 7 days and the Early Blue pea 5 days. Mandarin soy bean and Laurel oats did not approach the level of the others but were included for comparison.

CONCLUSIONS

Of the seeds tested in the present investigation, the Chinese Salad bean appeared to have the greatest range of adaptability combined with rapid production of vitamin C. However it is not available in sufficient quantities to warrant its recommendation for use on a large scale. The field pea varieties, Early Blue (Ottawa No. 21), O.A.C. No. 181, and Arthur produced appreciable amounts of antiscorbutic in 5 days and are readily available. The English Windsor broad bean is in less favourable supply but showed considerable merit with respect to vitamin C production, particularly at the lowest temperature.

The method of germination to be employed will be determined by circumstances and should be investigated in greater detail. Experience gained from the present experiments indicated the desirability of temperatures between 15 and 22° C. (60° and 72° F.) and of importance of drainage and aeration for the germinating material.

ACKNOWLEDGMENTS

The authors are indebted to Dr. L. H. Newman, Mr. M. B. Davis, Dr. T. M. Stevenson and Mr. J. G. Davidson of the Department of Agriculture, and Mr. J. R. Weir of the Ontario Agricultural College, who supplied much of the seed used in the investigation.

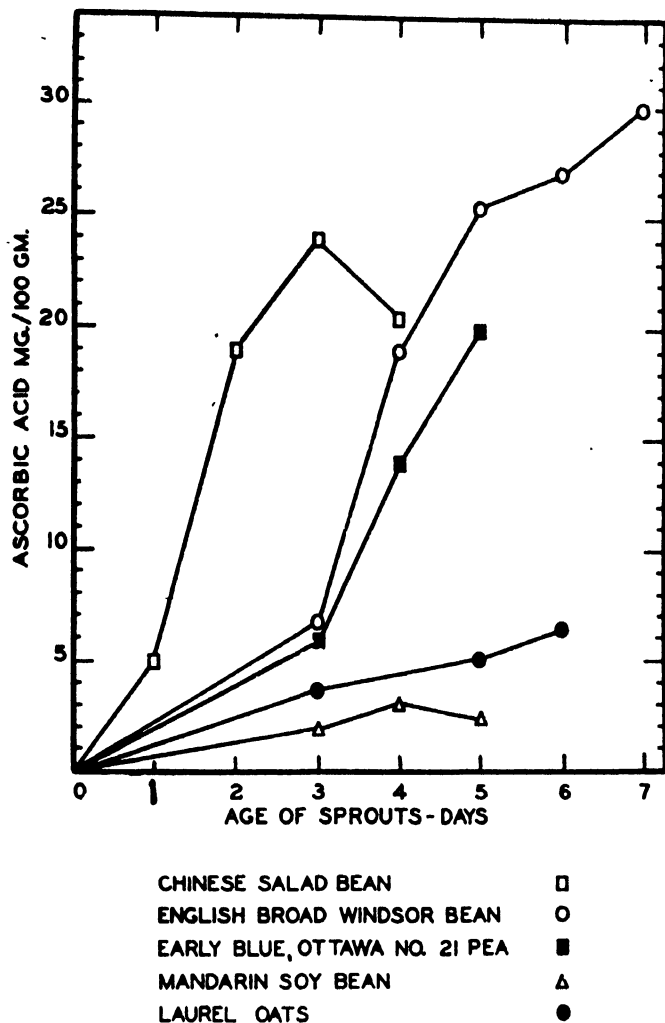


Figure 1.—Vitamin C production of selected seeds at 15.6°C. (60°F.)

REFERENCES

1. CHICK, H. and E. M. DELF. The antiscorbutic value of dry and germinated seeds. *Biochem. J.* 13 : 199-218. 1919.
2. BEESKOW, H. C. Bean sprouts: their preparation and properties. *Mich. State College Agric. Expt. Station Tech. Bull.* 184. 1943.
3. BONNER, J. and D. Bonner. Ascorbic acid and the growth of plant embryos. *Proc. Nat'l Acad. Sci. U.S.* 24 : 70-75. 1938.
4. REID, M. E. Localization of ascorbic acid in the cowpea plant at different periods of development. *Am. J. Botany*, 24 : 445-447. 1937.
5. SHERMAN and SMITH, *The Vitamins*, 2nd Edition. The Chemical Catalogue Co. 1931.
6. Council for Industrial and Scientific Research, Nutrition Laboratory, University of Adelaide, 1942. "The production of antiscorbutic by germinating peas".

LEGUME AND CEREAL SPROUTS AS A DIETARY SUBSTITUTE FOR FRESH VEGETABLES¹

W. A. ANDREA², EDITH A. CHALMERS², AND W. D. MCFARLANE³

Macdonald College, (McGill University) Quebec

[Received for publication February 2, 1945]

Cereal and legume sprouts have been used as food for many centuries in the Orient, and records also exist which show that the early explorers cured or prevented scurvy by eating sprouted peas and beans when fresh vegetables were not available. Soybean sprouts have recently received much publicity in the United States as the result of investigations by Professor C. M. McCay of Cornell University.

Dry seeds, in general, are devoid of ascorbic acid, but the seedlings contain a considerable amount. Burkholder (1) reports an appreciable increase in riboflavin and other members of the vitamin B-complex during the growth of corn, wheat, oats and barley seedlings. Sprouts have a flavour and nutritive value which approximates that of fresh vegetables and in addition, possess several advantages in that the seeds can be sprouted, ready for use in less than 10 days and their cultivation is not limited by season, climate, sunlight or soil. The only requirements are a fairly constant room temperature of about 70° F. and a good water supply.

It might be possible to supply a significant part of the daily requirements for ascorbic acid and vitamin B-complex by the use of sprouts in the diet and hence contribute to the solution of nutritional problems arising out of the difficulty in transporting fresh vegetables to troops in isolated areas and to the population of countries released from enemy occupation. Fresh vegetables are perishable and bulky and require rapid transportation and adequate storage facilities, whereas dry seeds may be shipped to the desired location and sprouted at their destination.

The primary aims of the investigations recorded below were (*a*) to devise simple and inexpensive methods for producing sprouts in bulk, even under adverse conditions; (*b*) determine the best time to harvest for highest vitamin content commensurate with palatability; and (*c*) prepare appetizing dishes containing sprouts.

MATERIALS AND METHODS

Sprouting

Good sprouts can only be obtained from good seed; broken seeds must be eliminated as they will constitute a centre for infection. Disinfectants, such as bleaching powder, at the low concentration of 1 tablespoon to 4 gallons of water, will destroy surface bacteria without harming the seed but will not prevent all bacterial growth; equally effective results were obtained with an abundance of fresh water. The sprouting was

¹ Macdonald College Journal Series No. 198.

² Graduate Research Assistants, Department of Chemistry, Faculty of Agriculture.

³ Professor of Chemistry.

carried out in a basement room with two small windows, a well-drained cement floor, and a good water supply. There was no provision for control of the room temperature which fluctuated from 66 to 73° F.

The seeds were soaked for 24 hours and held at a high humidity and a temperature of about 22° C. The most suitable container was found to be a 6-gallon lard tub with small holes in the bottom for drainage. The tub was half-filled with soaked seeds and covered with a lid to exclude light and to maintain a high humidity inside. The tub was filled twice daily with water and the seeds stirred by hand to break up the sprouting mass. The water drained through the holes in the bottom, leaving the sprouts moistened, washed and cooled. For smaller quantities, wide-mouthed fruit jars were used. The soaked seeds were placed in the jar and a piece of cheese-cloth was tied over the opening. The jar was filled with water twice daily, inverted to drain and allowed to remain in this position until the next watering.

These methods were not suitable for the cultivation of green shoots. In this case the soaked seeds were spread thinly on flat wire-screen trays, 14" × 22", supported at each corner by wooden legs, 7" high. These trays (Figure 1) are light and easy to handle and can be stacked to facilitate



FIGURE 1. Tray method of cultivating green shoots.

watering and utilize space. A layer of wood shavings on the screen increased the moisture retention and facilitated the cleaning of the trays after the shoots had been cut.

A portable container suitable for sprouting all types of seeds was made from a piece of coarse jute 40" \times 36" (Figure 2). The bottom of this bag measured 15" \times 19" and the sides were 6" high. Four sticks, less than 1" in diameter, were pushed through the open hems around the bottom, giving the bag considerable rigidity. Each corner was provided with a sling by



FIGURE 2. Portable container for sprouting all types of seeds

which the bag could be suspended by two poles or hooked to some convenient device. The bag was rendered rot proof by first immersing it in a 2% copper sulphate solution, then in 5% sodium carbonate solution and finally rinsing well with water. Rot proofing had no detrimental effect on the sprouting.

The seeds used were selected on the basis of (*a*) availability in Canada, (*b*) ease of sprouting, (*c*) nutritive value of the sprouts and (*d*) palatability of the cooked product.

Cooking

The authors considered as valuable any sprouts which were palatable and would serve to break the monotony of a diet depleted in fresh vegetables. However, such a diet is also likely to be low in vitamin C so the authors preferred to utilize sprouts of a high ascorbic acid content. Meals which included sprouts were prepared and served in the Macdonald College dining room. The final judgments of the palatability of the cooked food were obtained from C.W.A.C. personnel and College students, through the medium of a questionnaire.

The simplest cooking methods were employed. In boiling, the water was always brought to the boiling point, the sprouted seeds added, the container covered tightly and its contents brought back to boiling temperature as rapidly as possible. A minimum amount of water was used, but in cooking sprouted broad-beans they had to be almost covered with water to provide uniform cooking throughout. To preserve vitamin C emphasis was placed on preparing dishes which did not entail loss in the cooking water, e.g., soup, stew, baked dishes and fried dishes. The cooking water was saved for use in soup stocks, gravies or sauces.

Chemical Analysis

A. Ascorbic Acid

The determination of reduced ascorbic acid was carried out as follows:

Two 10-g. samples were ground with acid-washed sand and 25 ml. of normal-sulfuric acid containing 2% metaphosphoric acid. The extracts were centrifuged and washed three times with 20-ml. portions of the acid mixture. The combined extracts were made up to 100 ml. and aliquots were titrated against a standard solution of 2-6 dichlorophenol indophenol, as outlined by Burrell and Ebright (2). To analyze bean sprouts duplicate 25-g. samples were weighed out and transferred to a Waring Blendor with 100 ml. of the acid and reduced to a pulp within 8 minutes. The extracts were then treated as described above but the centrifugate and washings were made up to 200 ml. This method permitted the use of larger and more representative samples as each seedling weighed about 5 g.

When turbid or coloured extracts were encountered, making it difficult to detect the end point, 10 ml. of chloroform were well mixed with an aliquot of the extract and the titration completed, according to McHenry and Graham (3). On centrifuging, two layers were formed and the end point could be determined in the chloroform layer.

Total ascorbic acid determinations (reduced plus dehydroascorbic acid) were made on some of the samples, especially cooked products, employing H_2S reduction. The common procedure is to bubble H_2S through the extract for 15 min. and remove the H_2S with a stream of carbon dioxide or nitrogen. At least 2 hours are required to remove the H_2S , and frequently traces remain which reduce the indophenol dye and give results which are

too high. To completely remove the H_2S in a shorter time Fellenberg (4) heated the extract and Harris and Olliver (5) put the extract under reduced pressure. The authors found the following procedure, using the apparatus illustrated in Figure 3 to be most satisfactory.

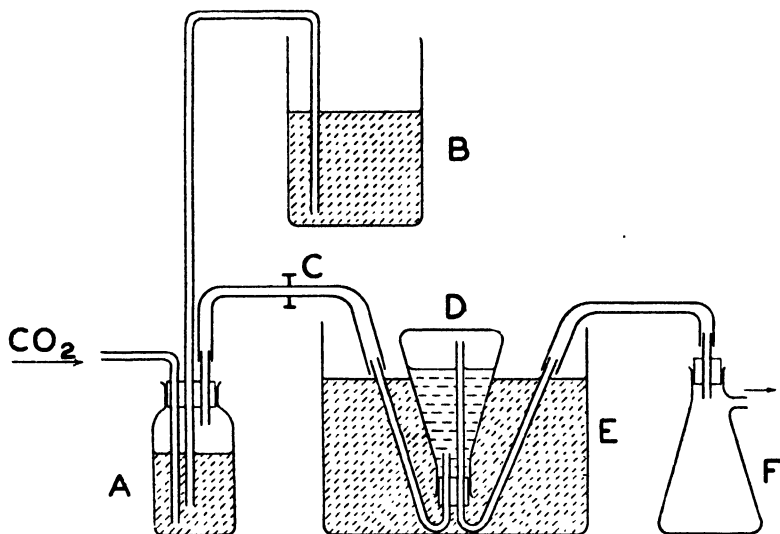


FIGURE 3. Apparatus for H_2S reduction of dehydroascorbic acid.

A 50-ml. aliquot of the extract, adjusted to pH 3.0, was transferred to a 125-ml. Erlenmeyer flask (D) fitted with a two-hole stopper, an aeration tube with head close to the stopper, and a glass tube extending to the bottom of the flask. The flask was inverted in a water bath (E) at $55^\circ\text{C}.$, and the H_2S entered through the aeration tube and escaped at the top by the long glass tube. This device ensured complete saturation of the solution with H_2S and prevented loss due to foaming. The reduction of dehydroascorbic acid was complete in 15 min. and the extract was then adjusted to pH 2.0 with 50% H_2SO_4 . The flask was replaced in the water bath and connected to a large bottle (A). CO_2 was admitted into A which was filled with water and the gas displaced the water into the elevated bottle (B). A pinch-cock (C) controlled the gas flow to D and the whole system was put under a reduced pressure of 100 mm. Hg. by applying suction to flask (F). In this apparatus the extract was freed from H_2S in 15 minutes at $55^\circ\text{C}.$

It is well known that the indophenol method is affected by the presence of other reducing substances in the extracts. Roe's colorimetric method (6, 7) employing 2,4 dinitrophenylhydrazine is said to be more specific and also determines dehydroascorbic acid. These methods were compared with the results shown in Table 1. In general the results agreed very well and did not indicate, so far as these samples were concerned, that any advantage would accrue from using the more complicated colorimetric procedure in place of the simple titration method.

TABLE 1.—ASCORBIC ACID DETERMINATIONS BY INDOPHENOL TITRATION AND BY THE COLORIMETRIC 2,4 DINITROPHENYLHYDRAZINE METHOD

	Ascorbic acid—mg. per 100 g.			
	Reduced		Total (reduced + dehydro.)	
	Titration	Colorimetric	Titration	Colorimetric
Broad Beans—sprouted 4 days	24.6	22.9	—	29.2
Vetch—sprouted 3 days	12.1	12.8	—	—
Vetch (cooked 20 min.)	3.5	4.2	—	13.3
Peas—sprouted 10 days	20.5	19.1	21.9	24.5
Dehydrated Cereal Grass	41.2	43.5	—	45.7
Standard Ascorbic Acid Solution (50 mg. per 100 cc.)	50.00	49.8	50.0	50.3

B. Riboflavin

The riboflavin content of the sprouts was determined by the following method which combined certain features of the Chapman and McFarlane (8) and the Najjar (9) fluorimetric methods.

A 10-g. sample was weighed into a 250-ml. centrifuge bottle, 50 to 75 ml. of a 0.2% pepsin solution in 0.33% HCl were added and the mixture incubated overnight at 37° C. and in the dark. After adjusting to pH 4.5, using bromcresol-green as an external indicator, 0.1 g. of takadiastase was added and the incubation continued for 3 to 4 hours. The material was centrifuged, the supernatant transferred to a 100-ml. volumetric flask, the residue was twice washed with distilled water and the combined extracts made up to 100 ml. with distilled water.

5-ml. aliquots were shaken in a separatory funnel with 1 ml. glacial acetic acid and 2 ml. pyridine; 10 drops 4% potassium permanganate were added and after 1 minute 10 drops of 3% hydrogen peroxide. Finally, 5 g. anhydrous sodium sulphate and 10 ml. butyl alcohol were added, the mixture shaken thoroughly for 2 min. and centrifuged. The fluorescence of the pyridine-butyl alcohol phase was measured in a Coleman photofluorimeter. The fluorescence due to substances other than riboflavin was corrected for with a "blank" prepared by exposing the pyridine-butyl alcohol solution to intense ultra-violet radiations, for one hour, thus destroying riboflavin only. The fluorimeter was standardized by carrying out a determination with 5 ml. of a riboflavin solution containing one microgram of pure riboflavin.

EXPERIMENTAL

CEREALS

Cereal seeds are the most desirable from the standpoint of supply and low cost, but oats and barley have their seeds embedded in a coarse hull and are therefore not suitable for sprouting. Hullless oats and barley are now available, but the seed is still expensive and only small quantities are on the market. However, these were studied, along with rye and it was found that, after 3 days of sprouting, the optimum ascorbic acid content was 5-7 mg. per 100 gms. We investigated 5 common wheat varieties.

Red Bog, Thatcher, Apex, Regent and Marquis. When sprouted for 4 days, the ascorbic acid content remained low (1.5–2.5 mg. per 100 gms.) and reached a maximum of 5.5 mg. per 100 gms. at 10 days (Figure 4).

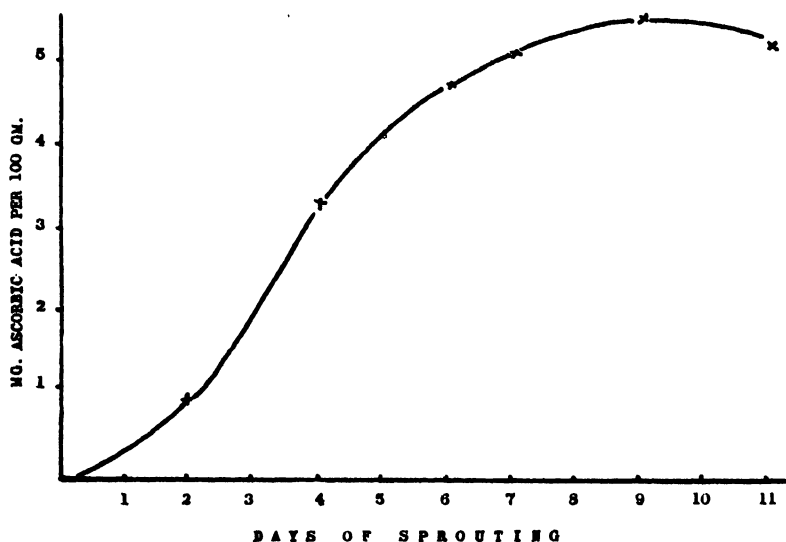


FIGURE 4. Showing the increase in ascorbic acid content of "Regent" wheat, during sprouting.

Cereal sprouts must be considered a poor source of ascorbic acid as 20–30% was lost on cooking for 10 minutes. Cereal sprouts alone were tasteless and had to be blended with oatmeal and served as porridge. It was found that after 3 days sprouting the roots were fibrous and unsuitable for human consumption, so that the sprouts could not be used at the stage of optimum vitamin C content. An attempt was made to remove the fibrous roots but the only practical method was to dry the sprouts, so that the roots became brittle and broke off on subsequent screening; this treatment destroyed the fresh food character of the sprouts.

LEGUMES

Legume seeds do not develop fibrous roots during the early stage of sprouting, and the entire sprout can be eaten up to the stage of the appearance of green leaves. At more advanced stages, only the green shoots are edible. Sprouted Mung beans have been used primarily for dietary purposes but the beans cannot be grown in Canada. Soybean sprouts have attained some popularity, particular emphasis being laid on the protein and ascorbic acid content. The ascorbic acid content of the soybean varieties we have studied was low, amounting to 10–15 mg. per 100 g. after 5 days sprouting. About 30% of the ascorbic acid was concentrated in the tender shoots and was readily leached into the cooking water. The loss after 20 min. cooking was about 50%, thus reducing the ascorbic acid retention to such a low value, that their value was questionable. Since a

great deal of information was already available on sprouting soybeans, we concentrated our efforts on other seeds.

1. Peas

The C. S. I. R. Nutrition Laboratory, University of Adelaide, Australia, recommended the use of Blue Boiler peas, sprouted for 4 days. They claimed a vitamin C content of 38 mg. per 100 g., of which one-third was lost on cooking. This variety is not available in Canada. It was found that, with the variety Ottawa 181, the ascorbic acid content increased to 15–17 mg. per 100 g., after 5 days sprouting. Because of the hardness of the seeds, it was necessary to cook the sprouts for 1 hour to render them soft enough to be palatable, with the result that 80% of the vitamin was destroyed.

To reduce this loss, field peas were sprouted for 10 days, during which time the seeds sent up shoots 8" long, so that the shoots could be clipped off close to the seeds and served as a green salad. This salad was agreeable to the taste and contained a significant amount of vitamin C. No advantage was found in prolonging growth beyond 10 days, as the shoots became fibrous and the ascorbic acid content declined. The distribution of ascorbic acid between the shoots, cotyledons and roots of pea seedlings at different stages of growth is shown in Figure 5. These sprouts were grown in a constant temperature chamber at 28° C. and 50% relative humidity. The sprouts grew rather poorly because of the low humidity. For comparison, the ascorbic acid content of seedlings from the same seed grown at 90% relative humidity, is also given in Figure 5.

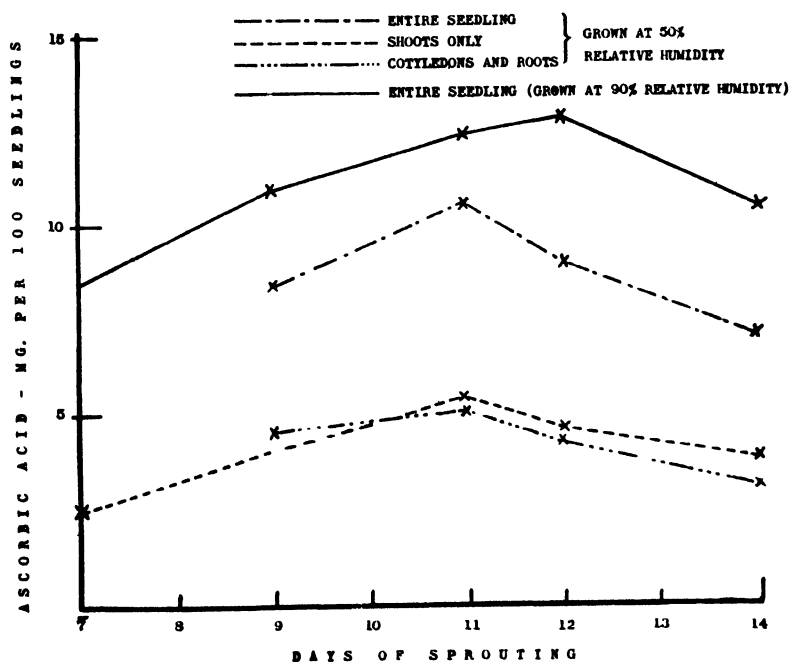


FIGURE 5. Distribution of ascorbic acid in pea seedlings.

The effect of light on sprouting was next studied, the most apparent response being the attractive green colour and retarded growth; the ascorbic acid content per 100 g. of seedlings was unaffected and an apparent increase in the ascorbic acid content due to light was offset by the lower yield. Ascorbic acid synthesis increased only when the light intensity reached a level which permitted photosynthesis. The effect of light can be seen from the data in Table 2, which also shows that above 25° C. there is a decrease in the yield and ascorbic acid content of the green shoots.

TABLE 2.—THE EFFECT OF TEMPERATURE AND LIGHT ON VITAMIN C SYNTHESIS IN 11-DAY PEA SHOOTS

Treatment	Yield of shoots (gms.)	Ascorbic acid	
		(mg./100 gms.)	(Mg./400 gms. dry seed)
25° C. in light	442	27.0	112
27° C. in light	371	25.9	96
30° C. in light	286	25.9	74
21° C. in dark	515	22.9	118
26° C. in dark	431	22.5	97
30° C. in dark	305	22.2	68

The suitability of sprouting bags (Figure 3) for growing green shoots was investigated. Equal amounts of seed were spread on shallow trays and sprouting bags, and it was found that the yield was greater in the latter case, but the ascorbic acid content of the sprouts was almost identical (Table 3). Rot-proofing the bag prevented the roots from penetrating the material thus facilitating the subsequent cleaning of the bag, although the yield in the presence of the copper carbonate was much lower.

TABLE 3.—THE EFFECT OF DIFFERENT SPROUTING DEVICES ON VITAMIN C SYNTHESIS BY FIELD PEA SPROUTS

Sprouting time (days)	Treatment	Yield of shoots (gm.)	Ascorbic acid content	
			(mg. per 100 gm.)	(mg. per tray)
11	Shallow tray	590	26.6	157
11	Bag, untreated	730	24.5	179
11	Bag, CuCO ₃ treated	496	25.2	125

The results in Table 4 indicate the effect of the thickness of seeding the trays. The yield of shoots increased with increasing amounts of soaked seeds per tray. The thicker the stand the taller the shoots and thus the greater the yield of shoots per 100 g. of soaked seeds. The ascorbic acid content of the shoots increased with the density of the stand but declined when the stand became too thick. The amount of ascorbic acid synthesized per tray was highest where the greatest amount of soaked seed was used, but calculated on a basis of 100 g. of seed, the greatest efficiency was obtained when 1000–1100 g. of peas were spread on one tray.

TABLE 4.—THE EFFECT OF THICKNESS OF SEEDING ON THE YIELD AND ASCORBIC ACID CONTENT OF ELEVEN DAY PEA SPROUTS

Weight of soaked seeds. per tray (gm.)	Yield of shoots		Ascorbic acid content		
	(g. per tray)	(g. per 100 gm. soaked seed)	(mg. per 100 gm.)	(mg. per tray)	(mg. per 100 gm. soaked seed)
814	401	49.3	25.7	105	12.9
1014	597	49.0	29.2	174	17.1
1144	606	53.0	30.2	183	15.9
1414	783	55.0	25.5	199	14.0

The riboflavin content of pea sprouts was determined with the results summarized in Table 5. It is evident that these sprouts would not contribute significant amounts of riboflavin to the daily diet.

TABLE 5.—RIBOFLAVIN CONTENT OF FIELD PEAS BEFORE AND AFTER SPROUTING

Sample	Riboflavin (micrograms per 100 gm.)
Dry seed	93
5 day sprouts	131
11 day sprouts	89

Seeds and the sprouts were also treated with growth hormones, including the commercial preparations "Parmone", "Stop Drop", and "Auxilin 1". No beneficial effect resulted from their use at high or low concentrations.

After 10 days sprouting, the pea shoots are crisp and green and ready to serve as salads. These are prepared by clipping the shoots close to the seeds, cutting them into pieces 2-3" long and "tossing" with French dressing. Attractive and nutritious additions include chopped vegetables, such as tomatoes, radish, carrots, lettuce, cabbage, or sprouted soybeans, which have been boiled 20 minutes and chilled.

The residual seeds would not sprout again although they still contained an appreciable amount of storage nutrients and ascorbic acid. This part of the pea sprout represents a complete loss because of the fibrous consistency of the roots. In 10 days sprouting, 400 g. of dry seed produced about 400 g. of green shoots which contained about 120 mg. of ascorbic acid. Therefore, 100 g. of dry seed produced about 30 mg. of ascorbic acid in the form of edible shoots. An average serving as salad, was 40 g. which provided 12 mg. of ascorbic acid.

2. Navy Beans

The germination of Navy Beans was retarded by soaking; they had to be sprouted between moist towels or on wet sawdust. The seedlings,

sprouted for 5 or 6 days, contained 11–15 mg. ascorbic acid and 125 micrograms of riboflavin per 100 g. At 12 days a green shoot formed which contained 23–26 mg. ascorbic acid per 100 g. Unlike pea sprouts, the cotyledon of the bean sprouts grew up with the stem to a height of about 4 inches and remained tough and starchy and could not be used in a salad. The cooked sprouts contained only 3–4 mg. of ascorbic acid per 100 g. and therefore their use is not recommended.

3. Windsor Broad Beans

The Windsor broad bean (*vicia faba*), sprouted for 4 days, was recommended by Johnson and Young (10) for its high vitamin C content. We found that the beans could be sprouted in tubs, trays or bags. Tubs were preferred as the cleanest sprouts were obtained in high yield and with high vitamin C content (Table 6).

TABLE 6.—THE EFFECT OF DIFFERENT SPROUTING DEVICES ON THE VITAMIN C CONTENT OF WINDSOR BROAD BEAN SPROUTS

Container	Weight of edible sprouts*	Ascorbic acid content	
		(mg. per 100 gm.)	(mg. per lot)
	gm.		
Tub	2702	25.5	690
Open bag	2639	28.2	740
Tray	2511	22.8	573

* Produced in 4 days from 2800 g. soaked seed.

The best results were obtained by soaking the seed for 24 hours and watering twice daily (Table 7).

TABLE 7.—THE EFFECT OF WATERING AND SOAKING ON THE 4-DAY SPROUTING OF WINDSOR BROAD BEAN

Soaking time (hrs.)	Daily watering	Weight of edible sprouts from 800 gm. soaked seeds	Number of defective seeds
		gm.	
12	Once	785	22
12	Twice	871	19
24	Once	929	13
24	Twice	977	6

A number of vitamin C determinations were made on several batches of beans sprouted for varying periods of time. The results, presented in Table 8 show that the vitamin C content increased rapidly during the third and fourth day of sprouting. The variability in the results obtained was attributed to changes in temperature during sprouting. Experiments carried out in a constant temperature chamber indicated that the optimum temperature for highest ascorbic acid production was 25° C.

TABLE 8.—SHOWING THE VARIATION IN THE VITAMIN C CONTENT OF SPROUTED WINDSOR BROAD BEANS

Duration of sprouting (days)	Ascorbic acid—mg. per 100 g.*
2	7.1
3	23.1; 14.6; 23.6; 20.4; 17.5
4	25.6; 15.8; 22.0; 16.9
5	28.3; 22.5; 21.2
7	31.2

* Each value represents the analysis of a different batch of sprouted beans.

The size of the sprouts was related to their ascorbic acid content and the most suitable stage was found to be when the shoots had broken through the seed coat and attained a length of about 1 inch. Extending the sprouting time did not seem beneficial as micro-organisms spread rapidly and caused spoilage and discoloration of the sprouts. Some bacteria caused proteolytic decomposition which produced a disagreeable odour, while others acted on the carbohydrates of the seed, affecting mainly the appearance and, to a lesser extent, the flavour of the sprouted beans. The danger of contamination by pathogenic bacteria does not seem likely.

Riboflavin determinations indicated that Windsor Broad beans, after 2 days sprouting, contained approximately 1 microgram per gram of fresh material.

The cooked sprouts were utilized in many appetizing dishes. The tough seed coats impaired the acceptability of the beans as a vegetable, but they could be removed by blanching which is a tedious procedure but apparently the only practical one. This was done by dropping the sprouted seeds into boiling water and allowing them to stand for 5 minutes, draining and adding cold water. The seeds were allowed to stand for 3 minutes, when the water was again drained off. When cool, the seed coats had loosened and were easily slipped off. The loss of ascorbic acid in blanching amounted to about 10%. Beans with a disagreeable odour were discarded while those with brown spots were considered edible.

Broad beans were served as vegetable, casserol, stew, or as thick soup. In testing for palatability broad beans were served with tomato sauce to a group of C.W.A.C. personnel. Of 33 answers to a questionnaire twenty-eight considered the beans a tasty addition to the diet, while five disliked them. Twenty-five minutes cooking rendered the beans soft to the point of being mushy but a few remained whole and firm. This gave rise to the comment from a few people that the beans were under-cooked. This opinion was based entirely on texture as only a few minutes boiling is necessary to remove the raw flavour from the beans.

When served as a vegetable with green pepper sauce they were generally very well liked. It was suggested that the beans were too dry and broken up. This was overcome by serving with a more generous portion of sauce and by stirring as little as possible during cooking. Comments on the stew were generally favourable.

Vitamin C analyses on the prepared beans showed a loss of 30–50% of the ascorbic acid originally present in the sprouts (Table 9). Further reduction in the final product was due to dilution by ingredients not containing vitamin C. One helping of thick soup contained about 14 mg. of ascorbic acid.

TABLE 9.—THE VITAMIN C CONTENT OF VEGETABLE DISHES OF SPRÓUTED WINDSOR BROAD BEANS, AS SERVED FROM AN ARMY KITCHEN

Vegetable dish	Ascorbic acid—mg./100 gm.	
	Before cooking	After cooking
Mixed with tomato	20.5	12.1
Boiled as vegetable	25.5	11.3
Thick soup	20.2	7.6

4. Vetch

Vetch seed (*Vicia sativa*) belongs to the same plant family as Windsor broad beans (*Vicia faba*). The sprouts were equally high in vitamin C, containing about 25 mg. per 100 gm. after 4 days sprouting (Table 10). The seed coat of vetch was not as tough as that of Windsor broad beans, and they could be rendered edible by 20 minutes cooking. The taste of vetch sprouts was not as pleasant as that of Windsor broad beans so they were blended with meat or tomato. One serving of sprouted vetch blended with meat contained 5 mg. ascorbic acid, and when blended with tomato, about 14 mg.

TABLE 10.—THE ASCORBIC ACID CONTENT OF VETCH SPROUTS

Sprouting time (days)	Ascorbic acid (mg. per 100 gm.)	Sprouting time (days)	Ascorbic acid (mg. per 100 gm.)
2	7.3	4	28.2
3	20.5	5	37.4
4	23.4	6	27.5

5. Soybeans

For the reasons already mentioned the work done on sprouting soybeans was very limited. "Mandarin" soybeans (*Glycine Soya*) were soaked for 8 hours at 22° C. and transferred to the sprouting-tubs. A thin, metal lid was placed on top to exclude light and to maintain a high humidity inside. The sprouts were watered frequently, the water being at about 22° C., and stirred by hand to ensure uniform germination. After each watering the tubs drained slowly and completely thus drawing in fresh air. At the end of the sprouting period (4–5 days) the tubs were emptied into a large water tank where the seed-coats floated-off leaving the sprouted seeds ready for use. The data obtained in these experiments is presented in Table 11. It will be observed that the vitamin C content increased rapidly but failed to reach a high level, and the increase in riboflavin was very slight. The soybeans doubled their weight in sprouting.

TABLE 11.—ANALYSES OF SPROUTED SOYBEANS AT VARIOUS STAGES OF DEVELOPMENT

Sprouting time (days)	Sample	Cooking time (mins.)	Weight of 250 ml. sprouts (gm.)	Weight of 100 seeds (gm.)	Ascorbic acid (mg. per 100 gm.)	Riboflavin (μ g. per 100 gm.)
	Dry seed	—	188.5	17.64	—	—
1	Raw	—	165.5	38.74	1.5	76
	Cooked	60	—	—	1.1	60
2	Raw	—	175.5	40.95	3.2	—
	Cooked	55	—	—	1.8	—
3	Raw	—	146.5	43.29	6.0	—
	Cooked	60	—	—	2.2	—
4	Raw	—	125.5	51.17	10.4	89
	Cooked	40	—	—	1.5	40
5	Raw	—	105.0	66.16	11.4	—
	Cooked	20	—	—	1.7	—

It was interesting to note (Table 11) that the cooking time decreased with prolonged sprouting. This was a great advantage as it saved time and fuel. As a result of the shorter cooking time a higher vitamin C retention was hoped for, but this was not found to be the case. Unfortunately the cotyledon required considerable cooking, consequently the rootlets were overcooked. Thirty per cent of the ascorbic acid in the sprout was concentrated in the tender rootlet and this was readily leached into the cooking water.

Sprouted soybeans were served as a vegetable. The 4-day sprouts were about 2 inches long and the beans were clean and in good condition for serving. Before cooking, the beans were washed thoroughly with large quantities of water and as many of the skins as possible were floated off. The beans were first weighed then dropped into sufficient boiling salted water to cover. They were brought to a rolling boil and allowed to cool in this manner for 40 minutes. As a result of boiling, many of the seed coats came to the top and were skimmed off. At the end of the cooking time the beans were drained in a colander (this drainage water should be used in gravy, white sauce or soup stock) and mixed immediately with a tomato sauce.

Of 33 answers to a questionnaire, 13 liked the soybeans as served while 20 disliked them. The general opinion of the latter was that they were not thoroughly cooked. Our experience was that the beans were cooked from the standpoint of flavour but remained tough from the standpoint of texture. In a further experiment the sprouted beans were boiled for 20 minutes, chilled and served as a salad with chopped carrots, lettuce and mayonnaise. The general opinion was that the salad required too much chewing and the flavour was not well liked. Some, however, appreciated the chewiness, so it seemed that a taste for such a salad might be acquired.

DISCUSSION

The work herein described shows that there are definite limitations in the substitution of sprouts for fresh vegetables. We consider only three types of seed to be of practical importance, viz., field peas, Windsor broad beans, and vetch. Cereal sprouts can only be used in the early stages, i.e. up to 3 days of sprouting. They may then be blended with oatmeal and served as a porridge. Their best feature is their cheapness and abundance, but their nutritional value, so far as ascorbic acid is concerned, is too low to be recommendable.

The attractive appearance and agreeable flavour of pea shoots as a salad met with general approval. Their ascorbic acid content is also high and cooking losses are obviated. The cultivation of pea sprouts, however, takes twice as long as any of the other sprouts. They are the only seed which have to be germinated in thin layers which requires more space and more handling. A tasty and nutritious vegetable soup can be prepared from Windsor broad beans. The ascorbic acid content of the sprouts, originally high, may undergo a considerable loss before serving when cooked too long or not served immediately. The seeds are scarce and expensive. Vetch seeds can be sprouted in a manner similar to that used for Windsor broad beans, but they are not particularly appetizing when served alone. They are palatable when mixed with meat or tomatoes.

The Committee on Food and Nutrition of the American National Research Council (11) has laid down the level for the daily riboflavin requirement at 2.2 to 3.3 mg. for a man weighing 75 kilograms, depending on the degree of physical activity. Considering this as a liberal intake and assuming that 1.8 mg. is sufficient for optimum health, none of the sprouted seeds would contribute a significant amount of riboflavin to the daily diet. The Committee also recommends 75 mg. ascorbic acid daily for the same type of man regardless of his activity. Others (12) believe 30 mg. ascorbic acid is an adequate daily allowance. Recent studies indicate the lower level as being protective against scurvy. With this requirement in mind Windsor broad beans after 5 days' sprouting, common vetch after 4 to 5 days' sprouting and field pea sprouts after 9 to 10 days' sprouting can be recommended as good sources of vitamin C in the diet. One serving of these vegetables will supply one-half the daily requirement of vitamin C. Sprouted soybeans and cereals in the ready-to-serve dish do not contribute appreciable amounts of vitamin C; however, soybeans are valuable for their protein of high biological value and cereals for their vitamin B-complex, so they may be considered a valuable addition to the diet.

Considerable fluctuation was encountered in the vitamin C content of pea sprouts and broad bean sprouts. This was due to variations in the stage of development of the shoot and to changes in external factors during the sprouting period. Reid (13), working with cow pea seedlings, came to the conclusion that the ascorbic acid in the seedlings was partly synthesized from storage carbohydrates and partly through photosynthesis in the young plants. She believed that a simultaneous synthesis and utilization of ascorbic acid took place in the plant and stated that the rate of ascorbic acid breakdown depended on the metabolic rate of the plant. High temperatures increase the metabolic rate, thus explaining the highest vitamin C content in seedlings grown in light at low temperatures.

In our experiment with pea sprouts grown for 11 days, more ascorbic acid per tray was synthesized at 21° C. than at 30° C., while the light of two 100-watt lamps or ultra-violet light had no effect. The failure to increase ascorbic acid synthesis by light was possibly due to insufficient intensity to permit photosynthesis. Ultra-violet light does not stimulate photosynthesis and thus was ineffective in producing vitamin C. Beeskow (14) analyzed Mung beans after 4 days' sprouting and found less ascorbic acid in rapidly growing sprouts than in those which grew more slowly. No similar observation could be made in this work. On the contrary, two lots of beans were brought to the same stage of development in 3 and in 5 days respectively. In both cases the vitamin C content reached 20 to 25 mg. per 100 g.

Cooking methods had a pronounced effect on the vitamin C content of the finished products. Best results were obtained when the sprouts were dropped into a volume of boiling water just sufficient to cover the sprouts and heated rapidly to bring the water immediately back to the boil. The sprouts were cooked in as short a time as possible and served immediately and without draining of the cooking water. Nevertheless, 35 to 50% of the ascorbic acid was lost in quantity cookery for army purposes. A further reduction of the vitamin C in the vegetable dish as served was due to dilution with ingredients not containing vitamin C.

SUMMARY

Methods have been developed for sprouting cereal and legume seeds in bulk, and to utilize the sprouted seeds in the diet in the form of palatable dishes.

Wooden tubs were most useful for sprouting Windsor broad beans, vetch, soybeans and cereals, while shallow screen-bottomed trays were best for peas. An open bag was designed for use in mobile camps and it was found convenient for sprouting all types of seed. Acceptable dishes were prepared from Windsor broad beans, peas, vetch, soybeans and cereals. The beans were best served as a vegetable, thick soup or in stew; the peas in salad; the vetch in meat or tomato mixtures; soybeans in vegetable dishes or in salads; and cereals in porridge or with rice.

It was estimated that one serving (approximately 6 ounces as vegetable, 2 ounces as salad) of Windsor broad beans, vetch and pea sprouts would supply half the daily requirement of vitamin C. The amount of riboflavin is considered to be insignificant.

ACKNOWLEDGMENTS

This investigation was made possible by a grant from the Associate Committee on Army Medical Research of the National Research Council. Major Robert Kark initiated this project and has made many valuable suggestions throughout the course of the work.

REFERENCES

1. BURKHOLDER, P. R. Vitamins in dehydrated seeds and sprouts. *Science*, 97 : 562. 1943.
2. BURRELL, R. C. and V. R. Ebright. The vitamin C content of fruits and vegetables. *J. Chem. Educ.* 17 : 180. 1940.
3. MCHENRY, E. W., and M. GRAHAM. Observation on the estimation of ascorbic acid by titration. *Biochem. J.*, 29 : 2013. 1935.
4. FELLEBERG, T. V. Ascorbic acid determination in Swiss foods. *Mitt. Lebensm. Hyg.*, 32 : 135. 1941.

5. HARRIS, L. J., and M. OLLIVER. The reliability of the method for estimating vitamin C by titration against 2 : 6 dichlorophenolindophenol. *Biochem. J.* 36 : 155. 1942.
6. ROE, J. H., and C. A. KUETHER. The determination of ascorbic acid in whole blood and urine through the 2,4 dinitrophenylhydrazine derivative of dehydroascorbic acid. *J. Biol. Chem.* 147 : 399. 1943.
7. ROE, J. H., and M. J. OESTERLING. The determination of dehydroascorbic acid in plant tissues by the 2,4 dinitrophenylhydrazine method. *J. Biol. Chem.* 152 : 511. 1944.
8. CHAPMAN, R. A., and W. D. MCFARLANE. A proposed modification of the fluorimetric method for the estimation of riboflavin. *Can. J. of Res. B*, 20 : 82. 1942.
9. NAJJAR, V. A. The fluorimetric determination of riboflavin in urine and other biological fluids. *J. Biol. Chem.*, 141 : 355. 1941.
10. JOHNSON, L. P. V., and G. A. YOUNG. The production of vitamin C by sprouting seeds. *Natl. Res. Council of Canada, Report No. 5-5-43.*
11. Committee on Food and Nutrition, National Research Council of the United States. Recommended daily allowance for specific nutrients. *J. Amer. Med. Ass.* 116, 2601. 1941.
12. Health Organization of the League of Nations. Report by Technical Commission on Nutrition on work of the Third Session. *Bull. Health Organ. League of Nations*, 7 : 475. 1938.
13. REID, MARY R. Relation of temperature to the ascorbic acid content of cow pea plants. *Bull. Torrey. Bot. Club*, 68 : 519. 1941.
14. BEESKOW, H. C. Bean sprouts; their preparation and properties. *Michigan Tech. Bull.*, 184. 1943.

APPENDIX

RECIPES

Sprouted Broad Beans—As a Vegetable

Remove the seed coats from 22 pounds of sprouted Broad beans. Add enough boiling water to almost immerse (ca. 10 quarts), cover tightly with a close fitting lid, bring back to the boil as rapidly as possible and boil 20 minutes. Drain, saving the drainage water for soup stock or sauce; add butter, salt and pepper and serve immediately as a vegetable.

Beans cooked in this manner may be served with many variations of white sauce, e.g., green pepper sauce, cheese sauce, tomato sauce, curry sauce or many other well seasoned sauces.

Broad Bean Casserole

20 pounds shelled sprouted broad beans (22 pounds unshelled)
 4 quarts canned tomatoes
 2 pounds fat pork
 8 tablespoons salt
 8 onions chopped
 4-6 peppers chopped

Mix all ingredients except the beans, heat thoroughly and pour over the shelled beans. Bake in a moderate oven (350° F.) one hour, or until the beans are soft.

OR

Simmer gently over low heat three-quarters of an hour or until beans are soft, adding water if necessary.

Broad Beans in Stew

In preparing stew for 100 people, 10 to 12 pounds of shelled beans may be substituted for one of the usual vegetables. These are added one-half to three-quarters of an hour before the stew is removed from the heat. Dehydrated vegetables may be used successfully in stew if fresh vegetables are not available.

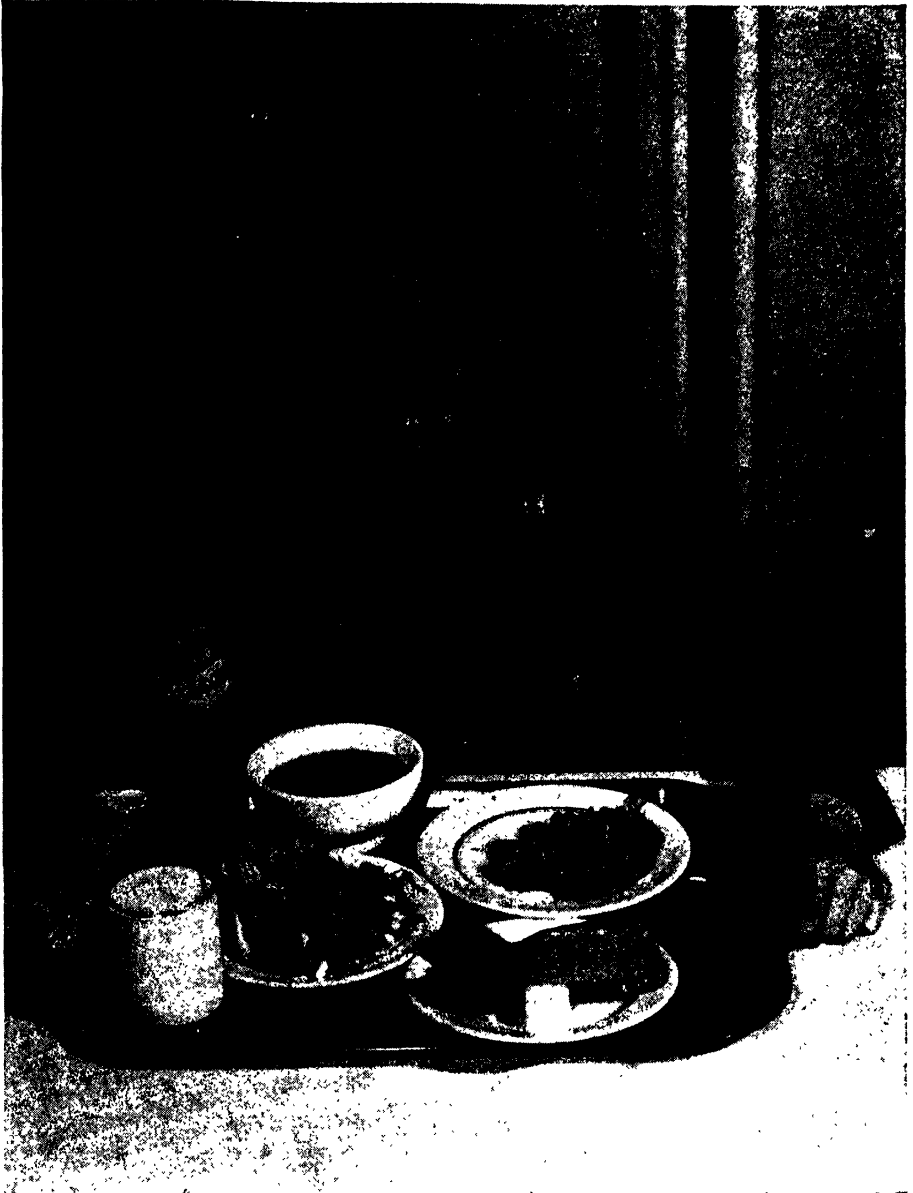


FIGURE 6. An appetizing and nutritious lunch including sprouted broad bean soup, pea sprout salad and sprouted broad bean casserole.

Broad Bean Soup

- 20 pounds shelled sprouted broad beans (22 pounds unshelled)
- 6 onions chopped
- 2 teaspoons celery salt
- 2 tablespoons chile powder (more may be added if desired)
- 4 quarts tomatoes
- salt
- pepper

Remove the seed coats from the beans, add chopped onion and enough boiling water (ca. 10 quarts boiling water to 20 pounds of beans) to almost cover. Boil rapidly one-half hour. Add tomato and seasoning and heat through, stirring to break up the beans. If soup is not thick enough, thicken with flour and butter or flour and water.

Chile Con Carne with Sprouted Broad Beans

10 pounds shelled broad beans
6½ pounds chopped onions
2½ pounds beef suet or other fat
20 pounds coarsely ground beef
5½ quarts stewed tomatoes
16 bay leaves
4 quarts water
1½ cups browned flour
13½ tablespoons chile powder
salt

Put fat in pan. Fry onions and beans 10 minutes,. Add other ingredients and cook about one hour. Thicken with browned flour. Season to taste.

Fried or Sautéed Sprouted Broad Beans

Fry about 20 pounds shelled beans and eight chopped onions in a small amount of fat about 5 minutes. Add a small amount of water and let cook 10 to 15 minutes longer. Serve as a vegetable.

Pea Sprouts—Salad

The 10-day shoots were cut as close to the seeds as possible; cut into convenient lengths (2–3 inches); tossed with French dressing and served. The recipe for the salad dressing was:

2½ tsp. salt
2 tsp. mustard
2 tsp. paprika
1 tsp. pepper
2 cups vinegar or lemon juice
4 cups olive oil

The bottom of a wide-mouthed pitcher was rubbed with onion. All ingredients were put into the pitcher and beaten until creamy with a Dover egg beater and served at once. This recipe provided enough dressing for 100 salads or more.

Attractive and nutritious additions to this salad were provided by the addition of chopped vegetables such as tomato, radish, carrot, lettuce, cabbage or sprouted soybeans which have been boiled 20 minutes and chilled.

The shoots were also cooked in a minimum amount of water, just enough to prevent burning, and served with butter, salt and pepper as a vegetable like spinach, but this is not recommended as cooking does not improve their quality and destroys a large percentage of the vitamin C.

Sprouted Wheat Porridge

1½ cups rolled oats
4½ cups water
4 cups sprouted wheat
½ tablespoon salt

Cook the rolled oats in the salted water 30–45 minutes; at the same time cook the sprouted wheat 10 minutes in water enough to cover, drain and add to the cooked porridge. This provides enough porridge for 13 people.

In preparing a vegetable from sprouted wheat, fry chopped onion and wheat in a small amount of fat 5–10 minutes. (Overcooking will cause the wheat to become very hard.) Add to this, cooked rice and heat thoroughly in the frying pan. This may be used if the supply of rice is short. When used in soup, drop the sprouted wheat into the soup 15 to 20 minutes before removing from the heat. The wheat has a sweet flavour and requires very little cooking. It may be substituted for rice but requires more chewing

ERRATUM

In the article entitled "A biological method of detecting the presence of fungicides on seeds" by H. W. Mead in *Scientific Agriculture* for March 1945 (Vol. 25, No. 7, pp. 458-461), the illustration on page 459 should bear the following legend.

"Figure 1. Showing the inhibitive effect of two mercury fungicides, carried on wheat kernels, on the growth of *Helminthosporium sativum* on potato dextrose agar. A, Ceresan series; B, Leytosan series. 1, untreated seed; 2 and 3, treated seed."

THE CHEMICAL COMPOSITION OF FEEDING STUFFS AVAILABLE IN CANADA¹

I. MOTZOK, D. C. HILL AND H. D. BRANION²

with the technical assistance of
W. D. M. GRAHAM AND H. W. SCHMALTZ
Ontario Agricultural College, Guelph

[Received for publication February 7, 1945]

Aside from a few early papers (Gamble and Harcourt (1), Shutt and Hamilton (7, 8), Shutt (6)), there appears to be no published data giving a survey of the composition of Canadian feeding stuffs. Therefore, it was thought that a compilation of this kind would be of considerable value to those interested directly or indirectly in the feeding of livestock.

Presented in this paper are the results of a survey carried out during the period 1939 to 1943 by the Department of Animal Nutrition, whereby 373 samples, representing 80 types of feeding stuffs were analysed for organic and mineral nutrients. The samples were from feeds which were available in Canada and which, with only a few exceptions, were produced in this country. The descriptive names of these feeding stuffs (meat meal, meat scrap, etc.) used herein are those under which the products were marketed.

METHODS OF ANALYSIS

The analyses for ash, crude protein ($N \times 6.25$), ether extract, and crude fibre were conducted according to the methods of the A.O.A.C. (4). Official methods were also used for moisture, with the exception of milk products which were dried to constant weight at 100° C. under atmospheric pressure.

The percentage of nitrogen-free-extract was obtained for each individual sample by subtracting from 100 the percentage of moisture, crude protein, ether extract, crude fibre and ash. It should be pointed out that where the analyses on certain samples in a group of feeding stuffs were incomplete the sum of the average values may only approximate 100%.

Destruction of organic matter, preparatory to analysing for calcium and phosphorus, was accomplished by digestion of the samples with nitric and perchloric acids as described by Gerritz (2). Calcium was determined by precipitation as calcium oxalate and titration with potassium permanganate. Phosphorus was determined by the method of King (3), the intensity of the blue colour being measured with a Cenco-Sheard-Sandford photometer.

For the determination of manganese, Schaible's modification (5) of the Willard-Greathouse method (9) was employed. The values are expressed as parts per million.

¹ Contribution from the Department of Animal Nutrition, Ontario Agricultural College.

² Head of the Department; at present on active service overseas with the R.C.A.F.

In the case of four types of feed where only one sample of each was available and determinations were not made for some of the constituents, the data were completed by the use of average values compiled by Morrison.³

DISCUSSION

In Table 1 the average, minimum and maximum values obtained for the various constituents are given for each type of feeding stuff. Where complete analysis was not obtained for every sample in a group, the number of samples analyzed is placed in parentheses just above the average value. It was thought that the calculation of the standard deviations was not warranted since in most groups the number of samples available for analysis was relatively small. However, the maximum and minimum values do provide a reasonably good indication of the wide variation in composition which, in many cases, was encountered within a group of feeding stuffs of similar type.

These variations may be attributed only in part to differences in the moisture content since they were not reduced appreciably by a comparison of the data on a "moisture-free" basis.⁴ It is likely that one or more of such factors as climatic and soil conditions, time of harvesting and method of curing, variety of grains and forage crops and milling and extraction processes were responsible for most of these variations.

Since average values are widely used for the purpose of estimating the nutrient content of individual feeding stuffs of mixed rations, it is important to emphasize that the composition of individual lots of the same type of feed may differ widely. Obviously, the use of averages may, in certain instances, lead to markedly erroneous results.

A large number of feeding stuffs come under the Feeding Stuffs Act and hence carry a maximum or minimum guarantee with respect to their content of certain nutrients. The use of such feeding stuffs for the preparation of a mixed ration of a specific composition is thus greatly simplified. However, the value as guaranteed may not always provide a reliable measure of the true content of the nutrient in question. Two examples may be cited from the present survey, one involving crude protein and the other, crude fibre content. Sixteen samples of meat meal, guaranteed to contain not less than 55% protein were analysed and six of these samples were found to be appreciably below this guarantee. Three of these six samples were below guarantee even when the protein was calculated on a "moisture-free" basis. Among 34 samples of various wheat by-products, nine samples exceeded the maximum limits for crude fibre for their class as designated under the Feeding Stuffs Act of 1937.

In view of the above considerations, it would seem advisable that, where a close approximation of the composition of a feed is desired, a chemical analysis should be carried out and average values should not be relied upon. On the other hand, where facilities are not readily available for such an analysis, average data, as presented in Table 1, can be of considerable worth, provided they are used with due regard for the number of samples analysed and the range in values which was found.

³ F. B. Morrison, *Feeds and Feeding*, Appendix, 20th Edition, 1936. Reproduced by permission of the publishers.

⁴ "Moisture-free" data are not presented in this paper.

SUMMARY

Eighty types of commercial feeding stuffs available in Canada were analysed for moisture, crude protein, ether extract, crude fibre, ash, calcium, phosphorus and manganese.

The significance and practical value of this compilation has been discussed.

ACKNOWLEDGMENTS

The authors are pleased to acknowledge the assistance given by D. Laughland, D. M. Young, and E. C. Roberts with certain phases of this project. They are also indebted to the numerous Canadian Feed manufacturers for their kind co-operation in supplying most of the samples used in this survey.

REFERENCES

1. GAMBLE, W. P. and R. HARCOURT. The composition of Ontario feeding stuffs. Ont. Agr. Coll. Bul. 138. 1909.
2. GERRITZ, H. W. Digesting biological materials for calcium and phosphorus analysis. Ind. Eng. Chem. Anal. Ed. 7 : 167. 1935.
3. KING, E. J. The colorimetric determination of phosphorus. Biochem. J. 26 : 292-97. 1932.
4. METHODS of Analysis, A.O.A.C. 1940.
5. SCHAIKLE, P. J., S. L. BANDEMER, AND J. A. DAVIDSON. The manganese content of feedstuffs and its relation to poultry nutrition. Mich. Agr. Exp. Sta. Tech. Bul. 159. 1938.
6. SHUTT, F. T., Farm Feeds. Dominion Exp. Farms, Bul. 36. 1919.
7. SHUTT, F. T. and S. N. HAMILTON. Commercial feeding stuffs. Dominion Exp. Farms, Bul. 47. 1921.
8. SHUTT, F. T. and S. N. HAMILTON. Meat and bone by-products. Dominion Exp. Farms, Bul. 49. 1925.
9. WILLARD, H. H. and L. H. GREATHOUSE. The colorimetric determination of manganese by oxidation with periodate. J. Am. Chem. Soc. 39 : 2366. 1917.

TABLE 1.—THE CHEMICAL COMPOSITION OF FEEDING STUFFS AVAILABLE IN CANADA

Feeding stuff*	No. of samples	Moisture	Crude protein	Ether extract	Crude fibre	N.F.E.	Ash	Calcium	Phosphorus	Manganese
		%	%	%	%	%	%	%	%	p.p.m.
<i>Animal Products</i>										
Blood Meal	5	Av. 10.0	84.4	1.1	0.7	1.1	2.8	0.33	0.30	5
		Min. 5.8	82.0	0.2	0.4	0.3	1.8	0.19	0.21	2
		Max. 11.4	85.8	4.1	1.0	2.0	3.9	0.54	0.41	12
Bone Meal (Feeding)	7	Av. 6.7	25.8	4.7	—	—	59.7	24.99	10.86	2
		Min. 3.6	22.1	2.1	—	—	54.1	21.40	10.21	1
		Max. 9.1	28.3	12.8	—	—	63.5	37.40	11.50	3
Bone Meal (Steamed)	5	Av. 3.3	7.6	1.6	—	—	80.5	29.10	14.26	8
		Min. 2.8	5.7	0.4	—	—	73.6	25.50	13.20	4
		Max. 4.2	12.2	4.0	—	—	84.5	31.60	15.00	16
Buttermilk Powder (Dried)	12			(8)†	(8)	(8)	(9)			(10)
		Av. 13.7	32.8	3.9	0.2	40.8	7.5	1.31	0.93	3
		Min. 4.2	30.0	1.3	0.1	31.9	5.7	0.97	0.90	0
		Max. 22.5	38.0	6.2	0.5	55.5	9.8	1.85	1.05	7
Casein	18			(14)	(3)	(3)	(17)			
		Av. 9.0	79.8	0.4	0.1	4.5	3.3	0.78	1.43	3
		Min. 7.2	68.8	0.1	0.05	0	1.7	0.05	0.75	0
		Max. 12.0	84.5	1.7	0.2	7.5	7.6	1.33	1.55	4
Cod Liver Meal	3	Av. 9.3	48.4	28.5	0.3	10.7	2.7	0.13	0.76	6
		Min. 6.0	43.7	18.3	0.1	6.8	2.1	0.03	0.68	5
		Max. 14.2	55.4	34.3	0.5	15.2	3.2	0.27	0.85	7
Cracklings (Cow)	1	10.9	57.2	9.4	1.2	0	23.0	7.42	3.77	28
Cracklings (Curb process)	1	6.7	53.5	8.8	2.8	0.6	27.6	9.00	6.46	14
Cracklings (Expeller process)	1	5.7	60.5	10.2	2.3	0.9	20.3	6.35	3.35	8
Cracklings (Horse)	1	6.0	57.7	9.7	0.9	3.3	22.4	7.16	3.78	3
Fish Meals (Unspecified)	7	Av. 8.6	62.4	6.4	0.6	4.1	17.9	5.33	3.28	12
		Min. 6.4	56.1	1.4	0.4	0.0	10.2	2.65	2.18	6
		Max. 10.6	70.3	15.2	1.1	8.7	24.7	8.05	4.48	18
Fish Meal (White)	5	Av. 8.4	67.2	1.9	0.5	1.5	20.7	6.76	3.69	11
		Min. 5.4	58.3	1.6	0.2	0.0	15.0	5.83	2.24	7
		Max. 10.4	71.6	2.3	0.8	3.1	26.8	8.55	4.73	20
Fish Meal (Herring)	1	7.6	68.3	4.2	0.3	9.9	9.6	2.49	2.08	10
Fish Meal (Pilchard)	3	Av. 9.6	65.8	9.1	0.8	2.5	13.6	4.04	2.72	9
		Min. 9.4	62.1	5.6	0.3	0.0	11.1	3.05	2.29	9
		Max. 9.9	71.1	11.9	1.5	5.3	15.1	4.58	3.04	9
Liver Meal	5	Av. 6.9	65.0	19.0	1.3	2.6	5.2	0.64	1.26	8
		Min. 6.2	61.0	18.1	1.0	0.0	4.4	0.07	1.09	6
		Max. 7.2	67.8	19.9	1.6	8.0	6.9	1.52	1.57	10
Lung and Liver Meal	1	Av. 6.8	61.1	21.9	1.7	0.7	7.8	1.68	1.47	6
Meat Meal (55% protein or over)	16			(9)	(9)	(9)	(12)			
		Av. 6.4	55.1	10.3	2.4	1.6	23.1	8.25	3.48	7
		Min. 4.1	49.5	9.2	0.8	0.0	17.5	7.72	1.01	2
		Max. 8.1	61.4	11.9	3.2	7.2	27.3	11.99	6.00	29

* The descriptive names of the feeding stuffs are those under which the products were marketed.

† Number of samples analysed.

TABLE 1.—THE CHEMICAL COMPOSITION OF FEEDING STUFFS AVAILABLE IN CANADA
—Continued

Feeding stuff	No. of samples	Moisture	Crude protein	Ether extract	Crude fibre	N.F.E.	Ash	Calcium	Phosphorus	Manganese
		%	%	%	%	%	%	%	%	p.p.m.
Meat Meal (below 55% protein)	17	Av. 6.7 Min. 5.2 Max. 8.5	49.3 45.3 54.6	(15) 11.7 9.4 14.9	(15) 3.7 1.7 5.1	(9) 2.4 0.0 5.8	(16) 27.3 21.3 34.2	9.04 7.07 11.21	4.79 3.10 5.59	(16) 7 3 13
Meat and Bone Meal	1	5.7	46.0	12.4	2.1	1.5	32.3	11.1	5.40	5
Meat Scrap	5	Av. 6.5 Min. 4.5 Max. 9.5	51.8 45.3 58.8	11.9 11.1 13.1	2.0 1.6 2.6	0.9 0.3 2.1	26.9 17.9 35.4	9.43 5.61 13.30	4.18 2.15 6.58	11 6 27
Milk Albumin (dried)	3	Av. 8.0 Min. 7.5 Max. 8.4	52.0 51.8 52.4	0.9 0.7 1.0	1.0 0.7 1.2	12.8 12.1 13.4	25.4 25.3 25.5	8.19 7.71 8.48	4.37 4.35 4.40	32 31 33
Skim milk Powder	6	Av. 9.4 Min. 5.8 Max. 12.7	32.9 30.4 35.3	(4) 0.4 0.2 0.6	(4) 0.1 0.1 0.1	(4) 50.3 47.8 54.7	5.9 4.5 6.9	1.13 1.07 1.26	0.96 0.88 1.08	(5) 1 0 1
Tankage	11	Av. 8.1 Min. 6.7 Max. 11.7	56.6 45.6 64.1	8.5 6.0 14.2	2.3 1.1 5.6	3.4 0.0 4.3	23.1 17.4 31.4	7.44 5.51 10.40	3.90 1.99 5.31	(10) 8 5 11
Whey Powder	1	11.3	24.2	3.5	0.2	54.6	6.3	1.26	0.94	3
<i>Cereals and Their By-products</i>										
Barley	7	Av. 12.1 Min. 11.8 Max. 13.1	12.4 11.7 13.6	(6) 2.2 1.8 2.7	(6) 5.6 4.5 7.7	(6) 66.0 65.2 67.0	(6) 2.2 1.8 2.5	0.08 0.05 0.19	0.46 0.31 0.50	16 14 18
Barley Feed	2	Av. 10.3 Min. 9.9 Max. 10.8	15.5 15.1 15.9	(1) 4.7	(1) 10.6	(1) 54.7	4.8 4.2 5.4	0.09 0.07 0.10	0.45 0.43 0.46	28 25 31
Buckwheat	2	Av. 11.5 Min. 11.3 Max. 11.7	11.4 11.3 11.6	2.8 2.6 2.9	11.0 10.8 11.1	61.4 61.3 61.5	1.9 1.9 2.0	0.08 0.07 0.08	0.34 0.33 0.35	31 30 32
Corn (African)	3	Av. 10.8 Min. 10.1 Max. 11.7	10.5 10.1 11.1	(2) 4.1 3.6 4.7	(2) 1.7 1.5 1.8	(2) 71.6 69.4 73.8	1.2 1.0 1.4	0.01 0.01 0.02	0.26 0.23 0.30	7 7 8
Corn (American yellow)	5	Av. 12.0 Min. 10.3 Max. 13.1	10.1 8.2 13.4	(4) 4.0 3.8 4.3	(4) 2.0 1.6 2.2	(4) 70.6 66.8 72.7	1.3 1.0 1.6	0.01 0.01 0.02	0.27 0.24 0.28	8 5 14
Corn (Argentine)	2	Av. 11.3 Min. 10.7 Max. 12.0	10.0 9.7 10.3	(1) 4.8	(1) 1.6	(1) 70.6	1.3 1.3 1.4	0.02 0.02 0.02	0.30 0.30 0.31	8 7 8

TABLE 1.—THE CHEMICAL COMPOSITION OF FEEDING STUFFS AVAILABLE IN CANADA
—Continued

Feeding stuff	No. of samples	Moisture	Crude protein	Ether extract	Crude fibre	N.F.E.	Ash	Calcium	Phosphorus	Manganese
		%	%	%	%	%	%	%	%	p.p.m.
Corn (Canadian yellow)	10	Av. 11.8 Min. 9.5 Max. 13.7	9.3 8.3 11.8	4.1 2.0 5.2	1.8 1.5 2.2	71.6 68.9 74.0	1.3 1.1 1.3	0.01 0.00 0.02	0.29 0.26 0.36	6 4 11
Corn (White)	3	Av. 12.7 Min. 10.6 Max. 14.4	10.1 8.6 12.5	(2) 4.1 3.7 4.5	(2) 1.9 1.8 2.0	(2) 68.8 66.3 71.4	1.1 0.9 1.2	0.01 0.01 0.01	0.25 0.20 0.29	5 3 6
Corn Germ Meal	1	9.8	19.6	5.8	10.4	52.3	2.1	0.04	0.47	19
Corn Gluten Feed	6	Av. 10.4 Min. 8.2 Max. 14.7	26.0 25.3 27.0	(4) 3.8 3.5 4.3	(4) 7.6 7.1 8.3	(4) 49.0 46.2 51.1	4.6 3.0 7.9	0.10 0.06 0.15	0.74 0.54 0.99	17 9 32
Corn Meal (Table)	1	13.9	7.6	1.3	0.3	76.5	0.5	0.00	0.11	2
Hominy Feed (White)	6	Av. 10.0 Min. 9.1 Max. 10.9	10.4 9.6 11.1	8.2 7.6 8.7	4.2 3.8 5.2	64.1 54.7 70.7	2.1 1.8 2.5	0.01 0.01 0.03	0.52 0.40 0.58	13 10 24
Hominy Feed (Yellow)	3	Av. 10.7 Min. 10.0 Max. 11.5	10.0 8.8 10.8	7.7 6.6 8.2	3.9 3.8 4.1	65.8 64.4 68.3	1.9 1.6 2.2	0.02 0.01 0.03	0.50 0.43 0.57	11 10 13
Oats (whole)	8	Av. 10.5 Min. 7.3 Max. 12.5	12.3 11.5 13.6	(7) 3.9 2.7 4.9	(7) 10.4 6.2 12.5	(7) 60.0 57.7 66.8	2.7 2.4 2.9	0.10 0.05 0.13	0.32 0.28 0.42	32 20 46
Oats (Rolled)	1	9.5	16.1	7.3	1.5	64.0	1.7	0.05	0.38	33
Oat Dust	1	8.1	18.0				4.7	0.14	0.49	95
Oat Groats	7	Av. 10.2 Min. 8.7 Max. 11.2	17.9 14.8 21.6	5.9 3.6 7.5	2.5 1.9 3.0	60.3 57.5 64.5	1.9 1.7 2.1	0.07 0.04 0.10	0.43 0.37 0.46	30 20 35
Oat Hulls	1	5.53	7.05	1.2†	30.6†	51.2†	5.7	0.12	0.18	20
Oat Meal	1	9.7	16.2	6.5	1.5	64.3	1.9	0.05	0.41	31
Oat Meal (Pinhead)	1	11.3	18.5	7.1	2.0	59.4	1.6	0.09	0.45	29
Oat Middlings	5	Av. 8.8 Min. 7.2 Max. 10.7	14.8 10.2 17.2	(4) 6.4 4.9 7.9	(4) 3.6 2.1 5.3	(4) 64.4 62.2 68.1	2.2 1.5 3.5	0.08 0.05 0.14	0.53 0.37 0.78	45 23 90
Rice Bran	1	12.8	8.2	13.4	10.5	57.7	7.3	0.45	1.19	176
Rye Middlings	1	11.2	17.5	2.7	5.4	60.3	2.9	0.06	0.63	44
Wheat	13	Av. 11.8 Min. 8.6 Max. 13.6	13.3 9.8 15.5	(11) 1.8 1.0 2.4	(11) 2.6 2.2 3.1	(11) 68.9 65.7 72.4	(12) 1.5 1.0 2.2	0.06 0.03 0.17	0.39 0.29 0.41	33 12 48

TABLE 1.—THE CHEMICAL COMPOSITION OF FEEDING STUFFS AVAILABLE IN CANADA
—Continued

Feeding stuff	No. of samples	Moisture	Crude protein	Ether extract	Crude fibre	N.F.E.	Ash	Calcium	Phosphorus	Manganese
		%	%	%	%	%	%	%	%	p.p.m.
Wheat Bran	9	Av. 10.6 Min. 8.8 Max. 12.2	16.3 14.1 20.4	(7) 4.5 3.1 5.4	(7) 11.6 10.0 13.8	(7) 52.7 48.8 58.1	5.8 5.1 6.4	0.11 0.10 0.16	1.27 1.15 1.47	113 78 140
Wheat Feed Flour	1	11.7	16.7	2.2	1.5	66.5	1.5	0.03	0.38	26
Wheat Germ	6	Av. 10.0 Min. 7.3 Max. 11.7	28.6 25.3 31.3	(5) 12.7 8.4 24.5	(5) 2.4 2.0 3.4	(5) 42.5 27.9 49.5	4.1 3.2 4.7	0.06 0.04 0.11	1.00 0.76 1.14	135 91 194
Wheat Germ (Defatted)	1	6.7	38.6	2.7	2.1	44.4	5.6	0.05	1.25	176
Wheat Germ Middlings	3	Av. 11.2 Min. 9.1 Max. 12.4	27.8 25.0 20.8	(2) 10.6 9.3 11.9	(2) 3.3 2.7 3.8	(2) 43.2 40.7 45.6	4.0 3.7 4.5	0.07 0.03 0.11	0.98 0.91 1.11	126 117 141
Wheat Middlings	7	Av. 10.8 Min. 9.5 Max. 11.8	19.2 16.6 21.9	(6) 4.9 3.8 5.4	(6) 4.8 2.3 6.1	(6) 57.9 55.7 63.3	3.0 2.2 3.7	0.07 0.04 0.09	0.69 0.46 0.80	86 52 108
Wheat Shorts	7	Av. 9.5 Min. 5.9 Max. 11.7	17.2 15.2 19.2	(6) 4.9 4.0 5.5	(6) 7.8 5.9 9.5	(6) 56.4 51.8 58.7	4.1 3.5 5.0	0.09 0.08 0.10	0.87 0.47 1.19	106 79 145
<i>Forages</i>										
Alfalfa (Dehydrated)	35	Av. 2.7 Min. 5.8 Max. 13.0	17.4 11.4 26.5	(23) 2.8 1.6 4.5	(23) 24.3 15.8 30.0	(22) 39.8 35.4 43.3	(23) 7.1 4.9 11.1	(34) 1.71 1.01 2.31	(34) 0.21 0.13 0.54	(34) 34 12 55
Alfalfa (Sun cured)	5	Av. 10.9 Min. 8.8 Max. 13.8	15.6 11.8 18.2	(4) 2.0 1.7 2.5	(4) 26.6 23.4 29.6	(4) 38.7 36.7 41.8	6.0 5.0 6.9	1.55 1.15 1.83	0.17 0.16 0.18	33 27 39
Cereal Grass (Dehydrated)	15	Av. 8.8 Min. 6.7 Max. 10.9	20.4 18.5 27.5	(12) 5.6 3.5 11.5	(12) 16.6 12.6 19.3	(12) 35.8 29.8 40.7	(13) 12.4 6.0 16.4	0.72 0.36 1.58	0.61 0.22 1.71	29 5 61
<i>Miscellaneous Feeding Stuffs</i>										
Alfalfa Silage (Dried)	1	5.8	17.2	2.4	29.4	27.4	7.9	1.57	0.86	—
Beet Pulp (Dried)	2	Av. 11.3 Min. 11.0 Max. 11.6	9.2 9.1 9.3	0.6 0.5 0.8	20.0 19.4 20.6	56.4 55.8 56.9	2.5 2.0 3.0	0.69 0.66 0.72	0.09 0.08 0.10	25 18 33
Brewers' Grains (dried)	1	8.0	22.8	4.0	24.9	37.5	2.9	0.19	0.33	33

TABLE 1.—THE CHEMICAL COMPOSITION OF FEEDING STUFFS AVAILABLE IN CANADA†
—Concluded

Feeding stuff	No. of samples	Moisture	Crude protein	Ether extract	Crude fibre	N.F.E.	Ash	Calcium	Phosphorus	Manganese
		%	%	%	%	%	%	%	%	p.p.m.
Copra Meal	1	9.9	21.1	6.5	18.8	38.7	5.0	0.11	0.58	61
Cottonseed Meal	6	Av. 8.2 Min. 7.0 Max. 9.5	40.1 37.6 42.1	6.4 5.7 6.9	10.5 9.5 11.6	28.2 26.8 30.1	6.4 6.1 6.9	0.16 0.13 0.20	1.35 1.29 1.39	18 17 20
Distillers' Dried Corn	1	7.9	28.8	4.0	13.8	43.5	1.8	0.03	0.43	14
Distillers' Dried Mixed Grains	1	7.4	30.7	6.0	13.5	41.0	1.4	0.04	0.28	35
Distillers' Dried Wheat	1	8.1	24.1	—	—	—	—	0.05	0.55	15
Feed Screenings	1	12.1	13.8	2.6	4.9	64.7	2.0	0.08	0.35	28
Flaxseed	1	8.2	20.8	36.4‡	5.9‡	24.2‡	3.6‡	0.34	0.60	15
Kelp Meal	1	13.4	8.2	1.4	11.6	50.7	—	1.14	0.16	2
Linseed oil meal	9	Av. 9.9 Min. 8.5 Max. 11.1	36.5 33.2 41.0	(7) 6.7 5.4 8.3	(7) 8.0 6.7 10.0	(7) 33.6 30.6 36.8	(7) 4.7 4.0 5.1	0.29 0.10 0.33	0.90 0.67 1.58	41 20 49
Malt Sprouts	2	Av. 11.0 Min. 8.3 Max. 13.8	26.7 23.7 29.7	1.4 1.4 1.4	13.7 13.3 14.1	41.9 41.7 42.0	5.4 5.2 5.5	0.25 0.18 0.32	0.76 0.74 0.78	35 15 55
Peas	2	Av. 12.6 Min. 12.1 Max. 13.1	24.1 23.0 25.2	1.1 1.1 1.1	4.7 4.4 5.0	55.4 54.8 56.1	2.1 1.7 2.5	0.09 0.08 0.10	0.43 0.27 0.59	30 13 47
Rapeseed Meal	1	7.6	32.7	5.1	11.7	30.4	6.3	0.47	1.00	42
Soybean Germ Oil Meal	1	6.9	38.5	—	—	—	3.7	0.12	0.64	24
Soybean Oil Meal	13	Av. 9.8 Min. 8.1 Max. 11.3	43.8 40.5 48.7	(9) 3.0 0.3 5.1	(9) 5.3 0.9 6.4	(9) 32.4 29.8 36.1	(10) 5.0 4.3 5.8	0.24 0.14 0.31	0.59 0.58 0.80	28 24 34
Starch	1	7.9	0.4	5.5	—	—	0.0	0.01	0.02	0
Sunflower Seeds	2	Av. 7.8 Min. 7.2 Max. 8.5	15.4 14.3 16.5	25.0 22.6 27.4	29.6 28.7 30.5	19.8 17.4 22.2	2.4 2.0 2.8	0.17 0.15 0.18	0.49 0.47 0.52	9 9 10
Sunflower Seed Meal	1	7.8	40.1	18.3‡	10.9‡	21.8‡	5.5	0.24	1.22	5
Tares	1	11.9	25.8	1.0	4.7	54.1	2.5	0.15	0.36	29
Yeast	7	Av. 7.3 Min. 4.4 Max. 11.1	49.8 38.8 57.5	(3) 0.8 0.5 1.3	(3) 2.7 2.1 3.6	(3) 37.0 29.1 43.0	(3) 7.6 7.4 7.9	0.09 0.05 0.13	1.64 1.21 2.19	6 5 10

† Values reproduced from *Feeds and Feeding* by Morrison, 1936, with the permission of the publishers.

COMMON SCAB OF POTATO IN DRY AND WET SOILS¹

G. B. SANFORD²

Dominion Laboratory of Plant Pathology, Edmonton, Alberta

[Received for publication February 16, 1945]

The relation of the water content of the soil to the incidence of common scab of potato is of general interest because of its direct effect on the vegetative growth and hyphal fragmentation of *Actinomyces scabies* (Thaxter) Gussow and also its effect on the associated soil bacteria and fungi.

It is not difficult to compare the growth of this pathogen in dry, medium, and wet soils, since inoculum of the fungus in a sterilized black loam soil produces an excellent vegetative growth under aseptic conditions.

EXPERIMENTAL

The soil containers for demonstrating growth of *A. scabies* in soils of different moisture content may be tight-fitting Petri plates, test tubes, or, if photographs are desired, small metal boxes, each fitted with a removable glass window and a hole in the cover. Metal boxes 5 × 5 × 7 inches were used for obtaining the data listed in Table 1. Soils of required moist-

TABLE 1.—THE OBSERVED VEGETATIVE GROWTH OF *Actinomyces scabies* IN A STEAM STERILIZED BLACK LOAM SOIL AT DIFFERENT SOIL MOISTURES

Soil water content*	Comparative growth rating†					Condition of soil
	Days after seeding soil					
	2	3	5	6	9	
%	%	%	%	%	%	
19	0	0	70	80	80	Very dry
22	0	0	80	90	90	
26	0	0	90	90	90	
30	0	0	100	100	100	Optimum
35	0	0	100	100	100	
39	0	0	20	60	90	Wet

* Approximate percentage of moisture holding capacity.

† Average of duplicates.

ure content were made up according to plan and steam sterilized in Erlenmeyer flasks, then aseptically poured into the sterilized boxes. When the container was about one-half full, a narrow band of soil next to the window was seeded with a very small quantity of soil-spore mixture, which was obtained by shaking a small amount of soil over a well matured culture of *A. scabies*. The containers were then filled to the top, the hole plugged with cotton, and the edges of the glass sealed with paraffin wax. The incubation temperature was 23° C. The moisture content of the soils in the different series was approximately 19, 22, 26, 30, 35, and 39% of their water-holding capacity. The first soil of this series was too dry for plant

¹ Contribution number 810, Division of Botany and Plant Pathology, Science Service, Department of Agriculture, Ottawa, Canada.

² Pathologist-in-Charge.

growth and the last one too wet to handle easily. Comparative ratings of the vegetative growth of *A. scabies* were made on the fifth, sixth, and ninth days after seeding with spores—a value of 10 representing the best growth observed on each date.

Five days after seeding, the observed growth in the dry soil was 30% poorer than in the soil of optimum or over-optimum moisture content, but about 70% better than that in the wet soil. However, one day later growth in the dry soil was only 25% better, and after three days the situation was

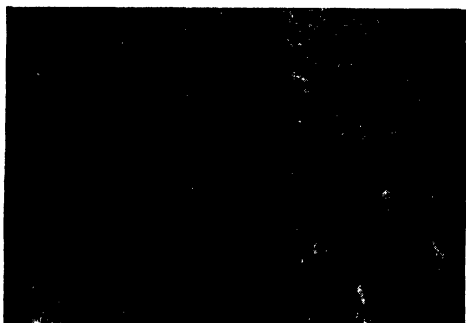


FIGURE 1. Above—Excellent growth of *Actinomyces scabies* in wet soil (39% m.h.c.). Below—Unseeded soil in which there are a few colonies from seeded strip.

reversed, with growth actually 12% better in the wet soil (Figure 1). Evidently the pathogen will grow surprisingly well in a soil too dry for plant growth, although it must be remembered that in a closed container the soil air would tend to be more humid than under field conditions. However, according to Lebedeff (3) the soil atmosphere is usually saturated under field conditions, except the surface layer, which occasionally becomes air-dry. Undoubtedly *A. scabies* grows faster and produces aerial hyphae more

profusely at optimum moisture content, although hyphal fragmentation is favoured by dry conditions and by aging.

DISCUSSION

The effect of soil moisture content on the incidence of potato scab may be conveniently reviewed under two headings, viz.: (a) growth of the pathogen in the absence of biological antagonism; and (b) in its presence.

The data in Table 1 are in general agreement with the results reported (7) earlier from growing *A. scabies* in a sterilized soil of different moistures and counting the colonies obtained from soil dilutions. Lutman, Livingstone and Schmidt (4) obtained the greatest number of colonies of *A. scabies* during winter from a field soil of high moisture content. Goss (2) concluded from his studies carried out in the greenhouse that "counts of *Actinomyces* in soil dilution plates and on soil slides did not check with each other, nor did either show any consistent relation to soil moisture or to scab". Sanford (6), 1923, reported severe scab in a naturally infested dry field soil an almost clean tubers in the same soil maintained fairly wet, and as a result of other laboratory experiments stated that "favourable conditions for growth of abundant inoculum and for subsequent growth would not be found either in an excessively dry or in a very moist soil, but in one of intermediate moisture content". It was thought "that in a dry soil sufficient moisture transpired from the tuber to enable spores adhering closely to the surface or about the lenticels to germinate and cause infection". In view

of the amount of growth noted in a dry soil in Table 1 the foregoing explanation still seems to have much merit. Of course if the soil were very dry before tuber formation, conditions would be definitely inimical to the viability and persistence of the pathogen and may result in a clean crop. Soil aeration in a dry soil under normal conditions would be excellent, and it is obvious that the oxygen supply would still be adequate for the pathogen until the soil became quite wet.

Let us now briefly consider antibiosis to potato scab in dry and wet soils. This factor was suggested (7) in 1926. Various degrees of compatibility and antagonism between *A. scabies* and a number of common soil bacteria were observed on solid and in liquid media, and it was concluded that these relationships would also occur in the soil. Subsequently (9) some common soil-inhabiting bacteria were shown to suppress, others kill, and still others to have no appreciable ill effect on the pathogen in a sterilized soil medium. Millard and Taylor (5) believed that *A. praecox* suppressed (by competition) the growth of *A. scabies* in their pot experiments, where grass cuttings were mixed in the soil, and they thought that bacteria might exercise a similar effect. Goss (2) reported no control from *A. praecox* in a heavily infested, steam sterilized soil, and Sanford (8) also obtained no control in a steam sterilized soil with or without green rye added. Dippenaar (1) found more *Actinomyces* than bacteria on slides buried in a dry soil, and the opposite in wet soil—which is not surprising. He concluded that the operation of bacterial antagonism to *A. scabies* in a wet soil explained why he obtained more scab in a dry soil than in one of high moisture content. Goss (2) obtained reduction of scab in a sterilized soil by adding organic manure or filtrates of unsterilized soil, and concluded that the reduction was due to a resulting increase of soil saprophytes.

Evidently biological antagonism must be accepted as an important factor in the production of inoculum of *A. scabies* in field soils. The evidence is also strong that it may be even more effective in reducing or preventing infection of the host. Obviously in a dry soil this antagonism would be severely reduced, whereas it would tend to become increasingly effective as moisture conditions and available nutrients became more and more suitable for the growth of soil saprophytes. This is especially true if soil bacteria are, in general, more antagonistic than fungi to the pathogen, as now seems probable. However, there seems no apparent reason why severe scab may not occur in soils of higher moisture content if the development of antagonistic micro-organisms in sufficient amount does not happen to be favoured by the existing conditions.

SUMMARY

The vegetative growth of *A. scabies* in steam sterilized black loam of six moisture contents, ranging from dry to wet, was observed during 9 days after 'seeding' the soil. It was always best at about optimum soil moisture, but surprisingly good in both dry and wet soils. At the beginning (5 days), growth in the wet soil lagged far behind that in the dry soil, but 4 days

later it was equally good or better. Thus, in the absence of effective antagonism from associated saprophytes, severe scab may be expected in soils high in moisture content, as well as in drier soils.

REFERENCES

1. DIPPENAAR, B. J. Environmental and control studies of the common scab disease of potatoes caused by *Actinomyces scabies* (Thaxt.) Gussow. Union of South Africa, Dept. of Agr. Sci. Bull. 136. 1933.
2. GOSS, R. W. The influence of various soil factors upon potato scab caused by *Actinomyces scabies*. Neb. Agr. Exp. Sta. Res. Bull. 93. 1937.
3. LEBEDEFF, A. F. The movement of ground and soil waters. Proc. 1st Int. Cong. Soil Sci. 1 : 459-494. 1928.
4. LUTMAN, B. F., R. J. LIVINGSTONE and ALICE M. SCHMIDT. Soil Actinomyces and potato scab. Vt. Agr. Exp. Sta. Bull. 401. 1936.
5. MILLARD, W. A., and C. B. TAYLOR. Antagonism of micro-organisms as the controlling factor in the inhibition of scab by green-manuring. Ann. of Appl. Biol. 14 : 202-216. 1927.
6. SANFORD, G. B. The relation of soil moisture to the development of common scab of potato. Phytopath. 13 : 231-236. 1923.
7. SANFORD, G. B. Some factors affecting the pathogenicity of *Actinomyces scabies*. Phytopath. 16 : 525-547. 1926.
8. SANFORD, G. B. Research on certain soil-borne diseases as affected by other micro-organisms. Sci. Agri. 19 : 609-615. 1939.
9. SANFORD, B. G. Soil-borne diseases in relation to the microflora associated with various crops and soil amendments. Soil Science: (accepted for publication). 1945.

FUSARIUM SAMBUCINUM FKL. F. 6 WR. AS A PATHOGEN OF SOME SPECIES OF THE CUCURBITACEAE¹

L. E. TYNER²

Dominion Laboratory of Plant Pathology, Edmonton, Alberta

[Received for publication February 16, 1945]

At Brooks, Alberta, in August, 1942, a number of vegetable marrow plants were severely wilted. Examination of the crown region of these plants revealed an extensive buff-coloured dry rot. A species of *Fusarium* was isolated from the stems and found to be very pathogenic to marrow. Dr. W. L. Gordon, of the Dominion Laboratory of Plant Pathology, Winnipeg, Manitoba, kindly identified the isolate as *Fusarium sambucinum* Fkl. f. 6 Wr. Only one reference (3) to this form as a pathogen of cucurbits was noted in the literature, and in that case it was reported as a cause of pumpkin fruit rot. The results of various tests of the pathogenicity of *F. sambucinum* f. 6 to marrows, squash, pumpkin, muskmellon and cucumbers are reported in the present paper.

METHODS AND RESULTS

Experiment I

In this experiment the effect of seed treatment upon infection by *F. sambucinum* f. 6 in various soils was investigated. Five samples of local soil were taken, viz., A, B and C, black loam in fallow, after wheat, and under sod, respectively; sample D, a leached soil, was taken from under poplar trees; and E, one rich in leaf mould, from under willow shrubs.

Each of the above mentioned soils was placed in 6-inch flower pots in the greenhouse, and 75 grams of soil-grown inoculum of the pathogen was mixed with the top 300 grams of soil. Fifty seeds of Imperial Long Green cucumber, treated with 1% by weight of 2% Ceresan dust, were planted in each of four replicated pots of each soil sample. A like number of inoculated pots were planted to 50 untreated seeds.

The average percentage emergence of the treated and untreated seed, respectively, 10 days after planting, was as follows: Soil A—16.4, 5.4; Soil B—8, 8.4; Soil C—17.4, 20.4; Soil D—38, 6.4; and Soil E—18, 18. The germination of this seed in a moist chamber was 94%.

The pathogen was very destructive in all cases and the effect of seed treatment was not so marked as it might have been under a less severe test. Seed treatments in Soils A and D appeared to be much more effective in reducing infection than was the case in the other three soil samples. The soils highest in organic matter (C and E) seemed to exert a protective effect against the pathogen independent of seed treatment. Moreover, the seedlings were most vigorous in Soil C and least vigorous in Soil B.

Experiment II

This experiment was an extension of the study on the effect of seed treatment. Twenty seeds of Imperial Long Green cucumber, 8 of Sugar pumpkin, 5 of Green Hubbard squash, and 5 of White Trailing marrow

¹ Contribution No. 811, Division of Botany and Plant Pathology, Science Service, Department of Agriculture, Ottawa, Canada.

² Agricultural Scientist.

were planted in 6-inch pots in the greenhouse. Forty grams of soil-grown inoculum of *F. sambucinum* f. 6 was mixed with 300 grams of soil from the top of each pot, and used to cover the seed. The seed for four replicated pots was treated with 1% by weight of 2% Ceresan by shaking in a flask and separating the seed from the excess dust. The seed for four additional replicated pots was untreated. All pots were placed in large metal trays to which water was added occasionally in an attempt to ensure equal moisture in all pots. In Table 1 the data on living plants are shown for 11 and 15 days, respectively, after planting.

TABLE 1.—EFFECT OF SEED TREATMENT ON THE INFECTION OF CUCURBIT SEEDLINGS BY *Fusarium sambucinum* F. 6 AT PERIODS OF 11 AND 15 DAYS AFTER PLANTING

Host plant	Living plants as percentage of seeds planted			
	Treated seed		Untreated seed	
	11 days	15 days	11 days	15 days
	%	%	%	%
Cucumber	35	40	12.5	17.5
Pumpkin	97	9	69	0
Squash	65	70	60	30
Marrow	100	10	0	0

An examination of columns 1 and 3 indicates a marked beneficial effect from seed treatment at the 11-day stage in the case of cucumber, pumpkin and marrow. The beneficial effect of seed treatment on squash is noted at the end of the fifteenth day. Marrow and pumpkin appear to be the most susceptible and squash the least, also it is apparent that the fungus is extremely pathogenic. In a greenhouse test of this nature, conditions are made to favour the pathogen at the expense of the host plant. It is probable that under field conditions, in a naturally infested soil, seed treatment would protect cucurbit seedlings much more effectively than was the case in pots.

Experiment III

In this experiment a comparison was made of the pathogenicity of three cultures of *F. sambucinum* f. 6 isolated from an alfalfa root, a potato tuber, and a diseased marrow stem. Twenty seeds of cucumber, 20 of muskmelon, 5 of marrow, and 10 of pumpkin were planted in pots. Forty grams of soil-grown inoculum of the three fungus isolates was mixed with 300 grams from the surface soil of four replicated pots in each case. A like number of control pots received no inoculum. The pots were placed in trays to which water was added when necessary. The number of living plants at the end of 15 days is indicated in Table 2.

Of the three strains of *F. sambucinum* f. 6 under test, only the strain from marrow demonstrated pathogenicity, which was very marked. The criterion of pathogenicity (2) was used to identify physiologic races of *F. niveum* on watermelon. Apparently a similar situation exists in the

TABLE 2.—RELATIVE PATHOGENICITY OF THREE STRAINS OF *Fusarium sambucinum* F. 6 TO CUCUMBER, MUSKMELON, MARROW AND PUMPKIN

Host plant	Living plants 15 days after planting as percentage of seeds planted			
	Strains isolated from			Control
	Alfalfa	Potato	Marrow	
	%	%	%	%
Cucumber	77	75	29	75
Muskmelon	78	80	0	75
Marrow	85	85	0	85
Pumpkin	72	72	0	70

case of *F. sambucinum* f. 6. Miller (1) has recently reported on the wide variation in pathogenicity to muskmelons of mutants of a *Fusarium* culture similar to *F. bulbigenum* var. *niveum* f.2.

Experiment IV

The effect of soil temperature on the pathogenicity of *F. sambucinum* f. 6 to cucumber and pumpkin was noted in this experiment. One-gallon crocks of soil were suspended in tanks of water at constant temperatures of 25°, 20°, 15°, and 11° C. Four of the crocks at each temperature were inoculated by mixing 200 grams of soil-grown inoculum of *F. sambucinum* f. 6 with 800 grams of the top soil from the crock. Twenty seeds of cucumber were planted 1 inch deep in this mixture. The soil in four control crocks was not infested. The crocks were covered with discs of waxed paper until emergence of the seedlings. After 20 days' growth the plants were removed and 12 pumpkin seeds planted in the same soil without the addition of any more inoculum. The effect of temperature on host and pathogen is indicated in Table 3.

TABLE 3.—EFFECT OF SOIL TEMPERATURE (CENTIGRADE) ON THE PATHOGENICITY OF *Fusarium sambucinum* F. 6 TO CUCUMBER AND PUMPKIN SEEDLINGS

Days after planting	Living plants as percentage of seed planted							
	Non-inoculated soil				Inoculated soil			
	25°	20°	15°	11°	25°	20°	15°	11°
	%	%	%	%	%	%	%	%
<i>Cucumbers</i>								
7	85	18	X	X	20	0	X	X
10	85	50	X	X	38	19	X	X
12	86	51	4	X	36	21	X	X
16	86	53	9	X	14	13	3	X
20	86	55	10	X	8	10	4	X
<i>Pumpkins</i>								
5	87	17	X	X	85	17	X	X
9	87	85	85	X	93	95	88	X
13	87	85	87	X	0	15	88	X

X — No emergence.

Soil temperatures from 11° to 15° C. were too low for satisfactory growth of cucumber seedlings. The pathogen was increasingly virulent from 15° to 25° C. Most of the seedlings in the infested soil were killed before they could emerge.

It is indicated that pumpkin is more tolerant than cucumber to low soil temperatures. Since a good emergence of the former occurred by the ninth day at 15° C., a comparison of the survival data of the pumpkin and cucumber plants in the infested soil indicates that the lack of fresh inoculum at the time of planting the pumpkin seed definitely reduced early mortality. However, the sudden wilting of the seedlings between the ninth and thirteenth days shows that the pathogen was still active in the replanted soil.

Experiment V

The data obtained from the greenhouse work were supplemented by field experiments. Seed of pumpkin, squash, and marrow were planted May 19 in 12-foot rows, replicated four times. Twenty-five seeds per row were planted and 150 grams of soil-grown inoculum of *F. sambucinum* f. 6 was added with the seed in the inoculated series. The weather subsequent to seeding was unsuitably cool and wet for these plants. By July 5 there were 76, 34, and 43 living plants of pumpkin, squash, and marrow, respectively, in the control rows, whereas the corresponding figures for the inoculated rows were 2, 8, and 0. Only 1 pumpkin and 3 squash plants were living by September 1. When the inoculum was placed in contact with the seed only a few plants escaped destruction in the seedling stage, and most of these succumbed at intervals up to and including the fruiting stage. In each case the plant wilted suddenly. Disease symptoms in the field and greenhouse were similar. That is to say, the tissue of the stem below the soil surface becomes necrotic, dry, breaks off easily, and is of a cream-buff colour.

The growth of the mycelium of the pathogen through the soil was demonstrated. Cucumber seeds were planted without inoculum added. When the plants were past the seedling stage (July 23), 50 grams of soil-grown inoculum of *F. sambucinum* f. 6 was placed at depths of 2 to 4.5 inches from the stem. At September 28, none of the 25 plants under test had wilted down, but all showed varying degrees of browning of the foliage, and few produced fruit. The pathogen was recovered in every case from the crown tissue by plating sections in nutrient agar.

SUMMARY

Fusarium sambucinum f. 6 was isolated from the stems of wilted marrow plants, and, in experiments in greenhouse and field, shown to severely attack and destroy the lower stem-portion of marrow, squash, pumpkin, muskmelon, and cucumber plants. Other isolates of this fungus from diseased potato tubers and alfalfa roots were not pathogenic to any of the cucurbits mentioned. Apparently this is the first record of a physiologic form of this species being a major pathogen to cucurbits. The gross symptoms of the disease are indicated.

REFERENCES

1. MILLER, J. J. Studies on the *Fusarium* of muskmelon wilt. I. Pathogenic and cultural studies with particular reference to the cause and nature of variation in the causal organism. Can. Jour. Res., C, 23 : 16-43. 1945.
2. SLEETH, BAILEY. Physiologic strains of *Fusarium niveum*. Phytopath. 22 : 24. 1932.
3. WOLLENWEBER, H. W., and O. A. REINKING. Die Fusarien. Berlin. 1935.

RIBOFLAVIN CONTENT OF CANADIAN FEEDSTUFFS¹

E. V. EVANS², D. M. YOUNG³, AND H. D. BRANION⁴

[Received for publication February 20, 1945]

The importance of riboflavin in livestock rations, particularly for poultry and swine, has been established and widely emphasized within recent years. As a consequence, this vitamin is one of the factors which must be taken into consideration in the compounding of these rations. It is well-known that certain ration components such as milk products and some high-potency fermentation products or by-products will supply the greater proportion of the ration requirement of riboflavin. Recently, pure crystalline riboflavin has been used successfully to replace a large part of the riboflavin from these sources. It is also true, however, that many other commonly used feedstuffs do contain appreciable amounts of riboflavin, and, depending upon the proportions in which they are included in rations, these materials can make small to moderate contributions toward meeting the required riboflavin levels in the rations. The amounts of the high-potency riboflavin sources required to be added will, therefore, depend to some extent upon the basic constitution of the rations. Another aspect which must be borne in mind is the variability in riboflavin content of feedstuffs of the same type.

The published literature records the results of many analyses of feedstuffs for their riboflavin content. As has been pointed out elsewhere (1), many published tables of vitamin values of feedstuffs quote only "average" values without any indication of the wide variations which may be encountered from sample to sample. Information of any kind on the riboflavin values of Canadian feedstuffs has been very limited.

This report presents information on the riboflavin content of miscellaneous Canadian feedstuffs with the major exception of milk products. The data reported herein have been accumulated during a period of approximately four years as a part of an analytical survey of Canadian feedstuffs. The results of the riboflavin studies on milk products have already been published (1). The results of the general chemical analyses of miscellaneous feedstuffs are reported in another paper (2).

EXPERIMENTAL

Many of the samples herein discussed were obtained directly from producers and distributors in response to requests for samples for this study. A much larger number represented bulk lots of feedstuffs obtained by departments of the College for use in routine and investigational feeding. The remaining few samples came to hand in connection with other aspects of the normal activities of the Department of Animal Nutrition. In all cases the samples represented feeding-stuffs produced or offered for sale in Canada. Complete information on the source and approximate date of origin for a majority of the samples is on file.

The microbiological assay method employed for the assays has been described previously (1). The remarks made at that time concerning the

¹ A contribution from the Department of Biochemistry, Ontario Research Foundation, Toronto, and the Department of Animal Nutrition, Ontario Agricultural College, Guelph.

² Formerly Research Fellow, Ontario Research Foundation; at present, Assistant Professor of Animal Nutrition, Ontario Agricultural College.

³ Formerly Graduate Student in the Department of Animal Nutrition, Ontario Agricultural College; at present, Technical Associate, Connaught Laboratories, University of Toronto.

⁴ Head of the Department of Animal Nutrition, Ontario Agricultural College; at present, on active service with the Royal Canadian Air Force.

relative reliability of the results are equally applicable to the present work. All determinations were conducted on the materials as received, and the results are expressed on that basis without any consideration of water content.

RESULTS

The results of the assays are consolidated in Table 1. Space does not permit the reporting of the potencies of the individual samples, but the inclusion in the table of the low and high observed values in addition to the mean values does serve to illustrate the extent of the variations encountered. Standard deviations have been calculated in those cases where 5 or more samples of a particular type of feedstuff were assayed. It should be pointed out that the values for the standard deviations are intended to serve only as indications of the variations in riboflavin potency of the samples studied, thereby compensating somewhat for the omission of the individual figures.

All the entries in the table were made on the basis of the identifying descriptions received with the samples. This means that the result for each material is included under the classification in which it was sold or offered for sale, regardless of whether or not the sample met the standards for that classification. Some few of the samples represented mixtures of unspecified proportions of two or more products. While these mixtures may not be typical of any well-defined classes of feedstuffs, they were included as a matter of interest. It should be pointed out also that the value of the figures reported for the "unspecified" samples of fish meal, liver meal and alfalfa meal is limited somewhat by the absence of complete information on the origin of these samples.

Perhaps the dominant feature of these results is the moderate to extreme variations in the riboflavin content of the "fair" to "good" riboflavin sources such as meat meal, fish meal, liver meal, alfalfa meal, cereal grass and yeast. The obvious variability of these feedstuffs emphasizes again the possible dangers in the use of so-called "average" riboflavin figures in the construction of rations.

It is possible that the variability in riboflavin content of processed feedstuffs might be reduced by more careful control of processing and by improvements in the methods involved. The establishment and enforcement of a system of guaranteed riboflavin levels for the important riboflavin carriers would undoubtedly be of value to the consumer, in that such would eliminate to some extent the uncertainty at present involved in the use of these materials.

SUMMARY

A total of 241 samples, representing a wide variety of types of feedstuffs of vegetable and animal origin (excluding milk products), was assayed for riboflavin content by the microbiological method. Fish meal, liver meal, meat meal, alfalfa meal, cereal grass, soybean oilmeal, and yeast were the feedstuff types which were represented by the largest numbers of samples. Low, high and mean values were recorded in all cases.

Rather wide variations in riboflavin content were found in many of the classes of materials.

Feedstuff	No. of samples	Riboflavin content (micrograms/gram)			
		Low	High	Mean	Standard deviation
<i>Feeds of Animal Origin:</i>					
Blood meal	8	0.1	1.1	0.5	0.30
Bone meal (feeding bone)	2	0.2	0.4	0.3	—
Cracklings:					
Cow	1	—	—	4.4	—
Horse	1	—	—	3.5	—
Fish meal:					
Pilchard	1	—	—	3.8	—
Whitefish	2	5.1	7.8	6.5	—
Unspecified	13	3.7	9.6	6.1	1.96
Hoof and horn meal	1	—	—	0	—
Liver meal:					
Cod	3	17	28	21	—
Pork	1	—	—	31	—
Unspecified	12	29	64	49	11.8
Lung meal	1	—	—	11	—
Lung and liver meal	3	13	21	18	—
Meat meal	44	2.4	8.2	4.6	1.42
Tankage	6	1.4	3.1	2.2	0.81
<i>Feeds of Vegetable Origin:</i>					
Alfalfa meal:					
Dehydrated	21	6.4	20	14	3.5
Suncured	5	7.0	11	9.3	1.69
Unspecified	4	5.3	11	8.7	—
Barley:					
Whole grain	3	1.3	1.3	1.3	—
Beet pulp	1	—	—	0.7	—
Cereal grass	13	11	18	15	2.5
Cereal grass + dehydrated alfalfa	1	—	—	15	—
Cereal + legume grass	2	12	15	13.5	—
Corn:					
Corn distillers' dried grains	1	—	—	3.1	—
Corn germ oil meal	1	—	—	3.0	—
Corn gluten feed	2	1.5	1.9	1.7	—
Hominy	3	1.3	2.8	2.0	—
Hominy feed	1	—	—	1.8	—
Whole grain	7	1.0	1.5	1.1	0.37
Cottonseed oil meal	3	2.3	3.8	3.1	—
Linseed oil meal	6	1.8	2.9	2.1	0.53
Oats:					
Groats	2	1.1	1.1	1.1	—
Whole grain	2	1.1	1.3	1.2	—
Rapeseed oil meal	1	—	—	1.8	—
Soybean oil meal	19	2.3	3.8	2.7	0.52
Sunflower seed oil meal	1	—	—	3.0	—
Wheat:					
Bran	6	2.6	3.6	3.0	0.40
Germ	2	5.3	5.7	5.5	—
Shorts	7	2.8	3.8	3.0	0.75
Wheat distillers' dried grains	2	2.1	3.3	2.7	—
Wheat distillers' dark grains	2	3.4	3.9	3.7	—
Whole grain	2	1.0	1.2	1.1	—
Yeast	22	2.7	89	36	20.6

ACKNOWLEDGMENT

The authors wish to express their appreciation of the co-operation shown by the many producers, distributors and others who furnished samples for this survey. The technical assistance of Miss E. D. Sparke in the conducting of many of the assays is gratefully acknowledged.

REFERENCES

1. EVANS, E. V., D. M. YOUNG and H. D. BRANION. Riboflavin content of milk products for feeding purposes. *Sci. Agr.* 24 : 510. 1944.
2. MOTZOK, I., D. C. HILL and H. D. BRANION. Chemical composition of feedingstuffs available in Canada. *Sci. Agr.*, 25 : 525-532. 1945.

PHENOTHIAZINE IN CODLING MOTH CONTROL¹

J. MARSHALL²

Dominion Entomological Laboratory, Vernon, B.C.

[Received for publication February 26, 1945]

Experiments with phenothiazine as a summer spray for control of the codling moth (*Carpocapsa pomonella* L.) were begun during 1937 and carried on until 1944 in the Okanagan Valley of British Columbia. As this project has been discontinued for the present, a review of the work may be useful.

LITERATURE

First reference to the high insecticidal value of phenothiazine was that of Campbell, Sullivan, Smith and Haller (1). As prepared in the laboratory by one of these authors, thiodiphenylamine (phenothiazine) appeared to be even more toxic to mosquito larvae than rotenone. The following year Smith and Siegler (6) experimented with phenothiazine for control of codling moth and reported that it was fully as effective as lead arsenate. Further laboratory work by Siegler, Munger and Smith (5) demonstrated that the initial toxicity of pure phenothiazine to codling moth was superior to that of lead arsenate. They concluded that as its cost should be relatively low for an organic compound, it should hold promise as an orchard insecticide. Newcomer (4), after two seasons' experience with phenothiazine in the field, stated that it was more effective in controlling the codling moth than any other material tried at Yakima, Washington. Used with soap it resulted in half as many wormy apples and one-tenth as many stings as an equal amount of lead arsenate with soap. He reported, however, that it reduced the red colour of apples to some degree and in hot weather had a tendency to irritate the skin of orchard workers.

Phenothiazine is not wetted by water and herein lies one of the difficulties in using the compound as an orchard insecticide. It is readily wetted by oil but it was thought for some time that a phenothiazine-oil mixture could not be used as a summer application because of the danger of foliage injury. Accordingly, adjuvants such as soap or sodium lauryl sulphate were suggested, but experiments showed that adhesion of phenothiazine was unsatisfactory with these substances. Not until it was used with stove oil did its exceptional toxicity to codling moth larvae become fully evident. It was discovered at the same time, that phenothiazine-stove oil mixture caused no more injury than phenothiazine alone.

According to Zukel (7), the action of phenothiazine on the cockroach is entirely one of contact. On the other hand, A. D. Heriot³, of the Vernon Laboratory, found that undiluted phenothiazine applied as a contact dust to codling moth pupae had no effect, whereas a dust of 5% sodium arsenite produced 98% mortality.

EXPERIMENTS IN BRITISH COLUMBIA

The field work with phenothiazine for codling moth control in British Columbia has been done in the Okanagan Valley where irrigation is a

¹ Contribution No. 2358, Division of Entomology, Science Service, Department of Agriculture, Ottawa, Canada.

² Entomologist in charge.

³ Unpublished work.

necessity and the temperature occasionally exceeds 100° F. The codling moth has a heavy second generation and in some years a partial third. At the present time its control in most orchards necessitates three lead arsenate and two cryolite spray applications, and in some cases fixed nicotine-oil is also used for late sprays. Casein-lime is the adjuvant with both lead arsenate and cryolite in order to ensure a powdery deposit that will not be difficult to remove with fruit wipers. Heavy spraying is the rule, in many orchards about one gallon spray liquid being applied in each treatment for each box of maximum crop production.

Hoy (3) has reviewed the experimental use of phenothiazine for codling moth control in British Columbia up to 1942. Results reported by Hoy, together with those for 1943 and 1944, are brought together in Table 1. The experimental plots varied in size from 6 to 10 trees; variety as a rule was McIntosh. Check plots adjoined the experimentally treated plots.

Data with respect to materials are:

Stove oil: 31.7 S.S.U. Vis. 100° F., 86% U.R. (A.O.A.C.)

Summer oil: 69 S.S.U. Vis. 100° F., 77% U.R. (A.O.A.C.)

Casein-lime: casein 10%, hydrated lime 90%.

Phenothiazine was obtained each year from Du Pont Chemicals, through Canadian Industries Ltd.

In 1937 and 1938 the phenothiazine was not micronized and contained a wetting agent of unknown composition. Control of codling moth was somewhat similar to that from lead arsenate-casein-lime on a pound-for-pound basis. A micronized product was obtained in 1941 and when wetted with stove oil and dispersed with soap (monoethanolamine oleate) this very finely divided material appeared to be about twice as effective as the phenothiazine applied previously. In 1942 when it was used in the same way but at reduced concentration and in all applications instead of the last two or three, it gave even more effective control.

Soap for dispersion of oil-wetted phenothiazine was not entirely satisfactory. It produced an unstable mixture that adhered strongly to the spray tank and spray hoses so that the amount of insecticide deposited on the fruit was less than indicated by its concentration in the tank. A hydrophilic colloid, casein-lime, was substituted for soap in 1943. That year, phenothiazine 1 pound per 100 Imperial gallons, wetted by stove oil 1 quart, when used in all cover sprays, resulted in better codling moth control than the standard growers' schedule consisting of lead arsenate 4 pounds, casein-lime 4 ounces, in early sprays and cryolite 4 pounds, casein-lime 4 ounces, in later sprays.

Micronized phenothiazine wetted with stove oil or summer oil and dispersed with casein-lime was applied to seven separate plots involving about 1.5 acres of large trees in 1944. Once again it proved at least four times as effective as lead arsenate or cryolite.

Although in all the British Columbia work the number of stung fruits was, with one exception, less in the phenothiazine plots than in the lead arsenate or cryolite checks, it did not drop to a degree comparable with the 1 : 10 ratio for total stings noted by Newcomer (4).

TABLE 1.—PHENOTHIAZINE IN CODLING MOTH CONTROL

Year	Materials per 100 Imp. gal.	Cover sprays applied	Percentage injured fruits	
			Stung	Wormy
1937	Phenothiazine 2 lb. (unknown wetting agent) Lead arsenate 3.2 lb., casein-lime 4 oz.	4	13.4	21.0
		4	15.6	5.1
1937	Phenothiazine 3 lb. (unknown wetting agent) Lead arsenate 3.2 lb., casein-lime 4 oz.	4	2.5	7.5
		4	1.5	2.5
1938	Phenothiazine 3.75 lb. (unknown wetting agent) Lead arsenate 3.75 lb., casein-lime 4 oz.	Last 2 of 5	3.0	2.2
		5	6.3	2.4
1941	Phenothiazine (micronized) 1.8 lb., stove oil 1 qt., monoethanolamine oleate 0.5 lb. Lead arsenate 3.75 lb., casein-lime 4 oz. Cryolite 3.75 lb., casein-lime 4 oz.	Last 3 of 6	5.6	9.8
		4}	9.8	10.9
		2}		
1942	Phenothiazine (micronized) 1.8 lb., stove oil 1 qt., monoethanolamine oleate 0.5 lb. Lead arsenate 3.75 lb., casein-lime 4 oz. Cryolite 3.75 lb., casein-lime 4 oz.	5	0.9	1.4
		3}	1.8	3.5
		2}		
1943	Phenothiazine (micronized) 1 lb., stove oil 1 qt. casein-lime 4 oz. Lead arsenate 4 lb., casein-lime 4 oz. Cryolite 4 lb., casein-lime 4 oz.	5	1.0	7.6
		3}	4.4	25.7
		2}		
1944	Phenothiazine (micronized) 1 lb., stove oil 1 qt. casein-lime 3 oz. Cryolite 4 lb., casein-lime 4 oz.	5	0.6	1.8
		5	0.7	2.8
1944	Phenothiazine (micronized) 0.5 lb., stove oil 1 qt., casein-lime 3 oz. Cryolite 4 lb., casein-lime 4 oz.	5	0.4	5.0
		5	1.1	3.6
1944	Phenothiazine (micronized) 1 lb., stove oil 1 qt., casein-lime 4 oz. Cryolite 4 lb., summer oil 1 qt. Cryolite 4 lb., summer oil 2 qt.	First 4* of 5	4.6	8.2†
		3}	8.8	8.8
		2}		
1944	Phenothiazine (micronized) 0.5 lb., stove oil 1 qt., casein-lime 4 oz. Cryolite 4 lb., summer oil 1 qt. Cryolite 4 lb., summer oil 2 qt.	First 4* of 5	4.8	6.2
		3}	7.4	9.8
		2}		
1944	Phenothiazine (micronized) 0.5 lb., summer oil 1 qt., casein-lime 4 oz. Cryolite 4 lb., summer oil 1 qt. Cryolite 4 lb., summer oil 2 qt.	First 4* of 5	4.6	7.8
		3}	8.8	8.8
		2}		

* Last cover spray fixed nicotine-summer oil.

† Infestation on these trees much heavier in 1943 than on those of succeeding two phenothiazine plots. That may have accounted for there being no apparent improvement in control in 1944 twice with the concentration of phenothiazine.

The most effective phenothiazine mixture was prepared by stirring phenothiazine into stove oil and in turn beating this mixture into an equal quantity of water-casein-lime mixture. The whole was then poured into the spray tank while the tank was being filled and with agitators in operation. In such a spray mixture the phenothiazine-stove oil is at first dispersed in huge and most unpromising flocs, but providing agitation is

adequate, the flocs gradually become smaller. No difficulty was experienced with the mixture either in stationary or portable equipment.

According to Cutright (2), phenothiazine favours development of the European red mite (*Paratetranychus pilosus* C. & F.) in Ohio. During 1944 this effect was also noted in British Columbia. For example, in one plot where phenothiazine was used, the average number of European red mites per leaf on September 5 was 33.6. The adjoining check plot sprayed throughout the season with cryolite-casein-lime (itself a mixture apparently favouring mite development) had an average number of 19.1 mites per leaf. A second phenothiazine plot averaged 41.8 mites and its adjoining check plot, 13.9 mites per leaf. Differences were consistent from tree to tree. In another orchard, it was apparent that phenothiazine also favoured development of the Pacific mite (*Tetranychus pacificus* McG.), although no population records were taken. If phenothiazine should come to be generally used for codling moth control, its unfavourable effect in so far as orchard mites are concerned will have to be taken into account. Evidently that effect may be offset to a large degree by use of fixed nicotine-summer oil for second brood application.

Under Okanagan Valley conditions, it is believed that micronized phenothiazine, if available at a reasonable price, could effectively replace lead arsenate which now is used only in early sprays. Since late applications of phenothiazine have a tendency to affect fruit coloration, second-brood phenothiazine sprays seem less suitable. Incidentally, elimination of lead arsenate from the Okanagan spray schedule is definitely desirable not merely because that compound leaves a highly objectionable residue on the fruit, but because it results in a toxic soil condition if heavily applied year after year.

SUMMARY

1. Experiments with phenothiazine for control of the codling moth (*Carpocapsa pomonella* L.) were carried on in British Columbia from 1937 to 1944. They have been briefly reviewed.

2. The phenothiazine used from 1937 to 1941 had about the same effect as lead arsenate against codling moth. The particle size of this material was evidently too great. When micronized, however, and used with a small quantity of stove oil, phenothiazine pound-for-pound was about four times as effective as lead arsenate.

3. Phenothiazine evidently favoured the development of European red mite (*Paratetranychus pilosus* C. & F.) and Pacific Mite (*Tetranychus pacificus* McG.).

4. Should micronized phenothiazine become available at a reasonable price it might help to eliminate lead arsenate from the British Columbia spray schedule for apples. It seems preferable to use it in early cover sprays rather than in the later applications.

ACKNOWLEDGMENTS

B. Hoy, Provincial Fruit Branch, Kelowna, B.C. collaborated in all work with summer sprays and many of the experimental data are from his plots. Oil specifications were determined by J. M. McArthur, Dominion

Division of Chemistry, Summerland, B.C. Also acknowledged is the work of E. P. Venables, A. D. Heriot and Harry Andison of the staff of the Vernon Laboratory, who did much of the spraying and fruit checking.

REFERENCES

1. CAMPBELL, F. L., W. N. SULLIVAN, L. E. SMITH and H. I. HALLER. Insecticidal tests of organic compounds—chiefly tests of sulphur compounds against culicine mosquito larvae. *Jour. Econ. Ent.* 27 : 6; 1176-1185. 1934.
2. CUTRIGHT, C. R. Populations of European red mite as affected by spray schedules. *Jour. Econ. Ent.* 37 : 4; 499-502. 1944.
3. HOY, B. Phenothiazine as a codling moth insecticide. *Proc. Ent. Soc. Brit. Col.* 40 : 11-12. 1943.
4. NEWCOMER, E. J. Phenothiazine, a promising new insectide [sic] for codling moth control. *Proc. 32nd Annual Meeting, Wash. State Hort. Assoc.*, pp. 119-120. 1937.
5. SIEGLER, E. H., F. MUNGER and L. W. SMITH. Laboratory tests of phenothiazine against codling moth larvae. *Jour. Econ. Ent.* 29 : 3; 532-537. 1936.
6. SMITH, L. E., and E. H. SIEGLER. Phenothiazine, a promising new insecticide. *Jour. Econ. Ent.* 28 : 4; 727-728. 1935.
7. ZUKEL, J. W. The insecticidal action of phenothiazine. *Science* 96 (2495) : 388. 1942.

FURTHER BACTERIOLOGICAL STUDIES RELATING TO EGG DRYING³

C. K. JOHNS² AND H. L. BEKARD³

Science Service, Ottawa, Ontario

[Received for publication March 15, 1945]

In a previous publication (9) the standards and procedures employed in the bacteriological control of Canadian dried eggs for export to Britain were described, together with some of the results for 1943. Studies conducted during the latter half of 1943 with the direct microscopic count (10) indicated that this method had considerable value in reflecting the care given the melange before drying. On the other hand, analysis of the results obtained in testing for the presence of coliform organisms and *Escherichia coli* indicated little or no correlation with plate counts of viable organisms, direct microscopic counts, the presence of *Salmonella* species or the results of plant sanitation surveys. The determination of coliform organisms and *E. coli* in Grade A powder was therefore dropped for 1944, a direct microscopic count of 2,000,000 per gram being substituted for it.

RESUME OF RESULTS OF 1944 OPERATIONS

As will be evident from the data in Table 1, the over-all picture as judged by the plate count of viable organisms was very satisfactory. The improvement in average counts over 1943 paralleled improvements brought about in the drying plants following plant sanitation surveys, supplemented by routine checks conducted by the resident inspectors using the Burri slant technique (8). With the direct microscopic counts, on the other hand, a very different picture was obtained. While gratifyingly low during the first four months, they then rose to quite high levels, remaining so until December. Had our analyses been confined to the plate count, we would have remained ignorant of the changed situation.

During the fourth week of May, unusually high direct microscopic counts appeared with dramatic suddenness in the powder from 3 of the 5 Western drying plants (Table 2). In each instance the high count was due to the presence of a short, plump rod, occurring in chains of up to 10 cells, and easily mistaken for a streptococcus. For convenience, this was referred to as the Y organism. It was never isolated from samples of powder received at Ottawa, while attempts to isolate it from numerous samples of melange and powder at the plants soon after the outbreaks met with no success. Plating powder on media containing sterile unheated egg, and incubating plates at temperatures ranging from 38° F. (3.3° C.) to 112° F. (44.4° C.) failed to bring about any significant increase over the standard plate count (1, 9), again suggesting that the organism did not survive the drying process.

In investigating this outbreak, samples were obtained from the start and finish of 3 days' drying at the two plants (A and C) where the Y organism first showed up, to determine whether or not any "build-up" in

¹ Contribution No. 204 (Journal Series) from the Division of Bacteriology and Dairy Research, Science Service, Dominion Department of Agriculture, Ottawa. Issued as paper No. 133 of the Canadian Committee on Food Preservation.

² Associate Bacteriologist.

³ Dairy Specialist.

count took place during the day's operations. (Previous experience had indicated the value of this practice in seeking the cause of high counts.) However, the results (Table 3) failed to indicate any consistent increase in count during the day's operations.

Because the appearance of the Y organism coincided with the change to a different batch of North's stain (1, 10), it was thought the explanation might lie in the ability of the new batch of stain to bring out this organism on stained smears, which previous batches had failed to do. However, subsequent comparative tests with old and new stains showed the Y organism to stain equally well with either, so this hypothesis had to be discarded.

The high counts due to the Y organism disappeared as suddenly as they had appeared. The organism appeared in powder made at 4 of the 5 plants in Western Canada, and was never seen in more than two carlots from any one plant. All available evidence suggested that the sporadic appearance of this organism in such large numbers could be attributed to its having invaded the contents of a small percentage of eggs; these being held at higher than average temperatures for longer periods than is customary, the organisms multiplied extensively without causing sufficient change in the appearance or odour of the eggs to enable the breaker to detect and discard them.

That high counts could be due to the eggs themselves, and not to faulty plant practice, was difficult to believe in view of the previous findings on the bacterial content of shell eggs as broken out in 2 Canadian drying plants (6, 7) supplemented by periodical counts at breaking and drying plants throughout Canada. Such findings had confirmed the conclusion reached by previous investigators that good quality shell eggs contain relatively few bacteria. However, evidence accumulated since May, 1944 has necessitated some modification of this view.

Shortly after the epidemic of high counts in the West, there was a general rise in the level of microscopic counts on powder from all over the country. This is clearly seen in Figure 1, showing the microscopic counts of consecutive carlot samples of Grade A powder. The general level of counts continued to rise until October, following which there was some decline. On the other hand, this seasonal rise was not evident in the plate counts (Figure 2 and Table 1). Since plant sanitation and practices were generally superior to those of the previous year, it seemed most unlikely that these higher levels of microscopic counts could be attributed to faulty plant operations.

The first indication that high counts might be coming from the eggs themselves was obtained in one of the Western plants at the end of May, 1944. This plant (Plant E) had had trouble with high counts for some weeks prior to the appearance of the Y organism (Table 2). Investigation revealed that, because of the extreme shortage of cold storage facilities, eggs had been broken directly out of cars, the temperature of which at times had exceeded 60° F. Melange prepared during the day was pumped into portable 80-gallon holding tanks and run into a cold room held at around the freezing point. Some of this melange would be held for up to

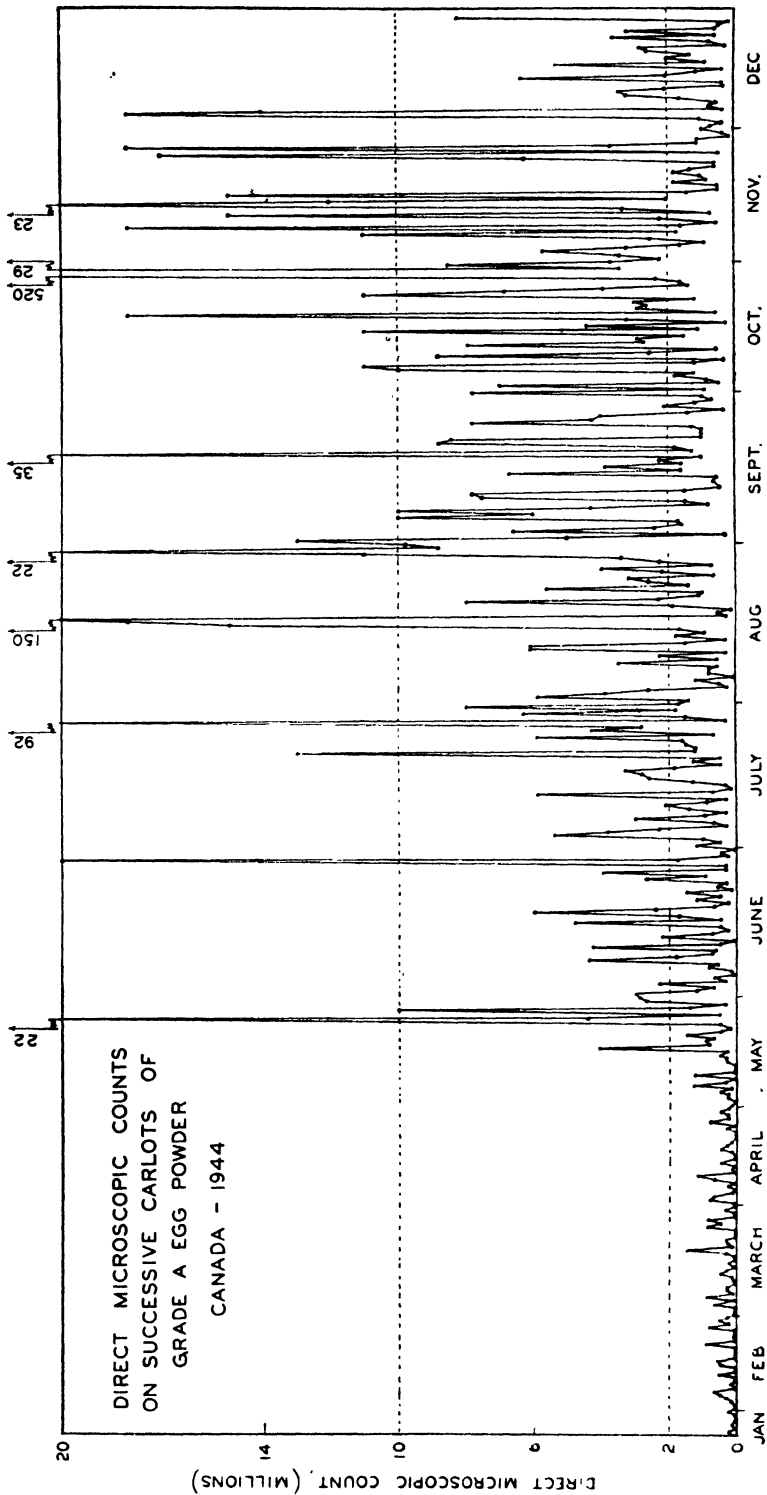


FIGURE 1. Direct microscopic counts on successive cartlots of Grade A egg powder, Canada—1944.

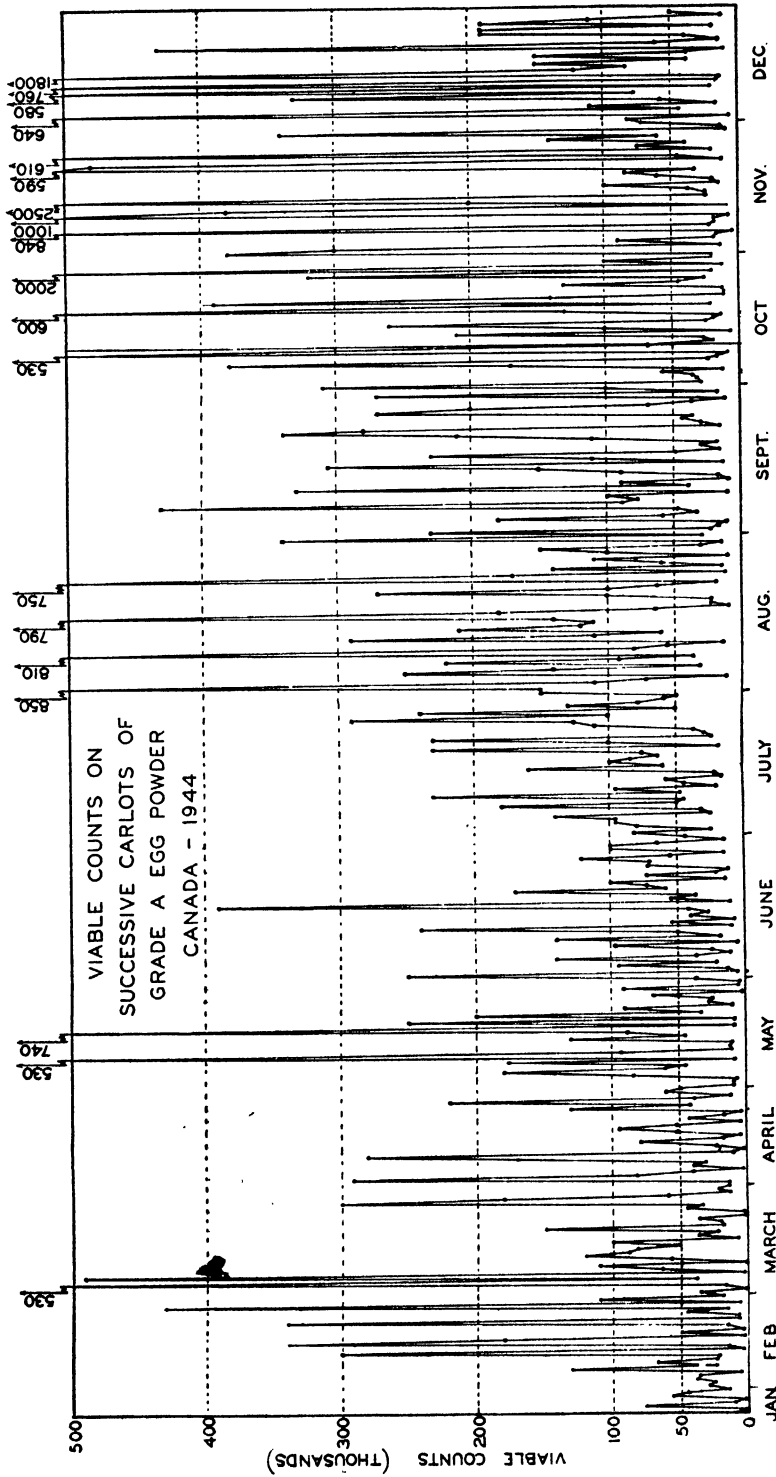


FIGURE 2. Viable counts on successive cartlots of Grade A egg powder. Canada—1944.

16 hours before being dried. With the slow rate of cooling of such large masses of viscous material in still air (2), considerable bacterial development could be expected.

This plant had two cars of eggs in storage; both had been "spotted" on May 15th and were held "on track" until unloaded on the 22nd. At that time temperatures of 60° and 65° F. were recorded inside the cars. These eggs were then placed in storage at 30° F. In order to get some idea of the bacterial content, it was decided to select 5 representative cases from each carlot, and to have these eggs broken by experienced breakers using specially sterilized equipment. This was done on May 29th. Six pailfuls of melange were then selected from each carlot, mixed as thoroughly as possible by beating with long handled spoons, and samples taken for analysis. From each sample a Burri slant was prepared and incubated at room temperature for three days. In addition, a direct microscopic smear was made using the technique of Mallmann and Churchill (12).

Because of the uneven distribution of bacteria on these smears, it was not possible to draw valid conclusions concerning the bacterial contents by microscopic examination. The Burri slants, however, (Table 4) indicated marked variations from one pail of melange to the next. Furthermore, it was significant that the high count slants showed practically pure cultures, in striking contrast to the heterogeneous flora obtained from swab tests on on breaking equipment (Figure 3). This strongly suggested that the high counts were attributable to the inclusion of an occasional egg which, while normal in odour and appearance, contained enormous numbers of bacteria.



FIGURE 3. Burri slants prepared from pails of melange (A to F) and from swabbing of a breaking cup (9).

Evidence pointing in this direction accumulated as the summer went on. Burri slant determinations made at breaking plants throughout Canada showed a much higher level of counts from May on without any evidence of a let-down in sanitation in the plants. Again, the chemist at one Ontario drying plant frequently broke out 90 to 100 eggs from a current carlot. Each egg was carefully checked for abnormality, then a Burri slant prepared. Occasionally the slant from a single apparently normal egg would be so heavily overgrown that it could not be counted, while the remainder would show few, if any, colonies. Slants made after beating the entire batch of eggs in a sterilized pail would show counts in the millions, and of the type of organism found on the slant from the high count egg. At this plant, later on in August, the writer prepared triplicate Burri slants from 30 pails of melange broken out with special precautions to reduce contamination, with the results shown in Table 5. Here again it was found that the high count slants showed practically pure cultures, strongly suggesting that a single egg was responsible for the high count on the painful of melange.

Although a number of independent breaking plants broke and froze eggs for subsequent drying, the volume of eggs handled by the Special Products Board in 1944 was so great⁴ that from early May on it was impossible to find sufficient first-class shell egg storage. Unfortunately, this coincided with the appearance of unusually warm weather, temperatures approaching or exceeding 90° F. being recorded in May from Quebec to Alberta. As a result, eggs were held for longer periods at higher temperatures than are recommended. Under these conditions, it is understandable that organisms capable of infecting and growing in the egg might multiply enormously before the egg was placed in proper cold storage. Subsequent growth would depend upon the ability of the invading organism to grow at around 30° F. The presence of a small proportion of such eggs, which could not be detected by appearance or odour, would account for the marked rise in counts noted.

EXPERIMENTS WITH ORGANISMS ISOLATED FROM HIGH COUNT EGGS OR MELANGE

In order to determine the infective ability of organisms isolated from individual eggs or carefully prepared melange, fresh eggs were obtained on several occasions through the courtesy of the Poultry Division, Central Experimental Farm. These were warmed for several hours at body temperature, then immersed for 1 to 2 minutes in cold suspensions of the organisms to be tested, after the technique devised by Haines and Moran (4) for infecting eggs without rupturing the shell. The cultures employed included species of *Achromobacter*, *Flavobacterium* and *Pseudomonas*. In the earlier experiments the eggs, after immersion in the bacterial suspensions, were held at 58 to 60° F. with a relative humidity of 50%. From 4 to 5 weeks later the eggs were broken out individually, using an ordinary egg breaking knife and cup which were washed, then treated in Roccal solution (1 : 500) for 2 minutes, after each using. The broken-out eggs were placed in sterile jars and examined for odour and appearance by members of the laboratory staff as well as by specialists from the Poultry Products Division,

⁴ Purchases during the first 6 months of 1944 were 212% of those for the same period of 1943.

Marketing Service, Department of Agriculture. On one occasion, 2 eggs infected with an *Achromobacter* species, and showing plate counts after 3 days at 86° F. (30° C.) of 2,500,000,000 and 2,800,000,000 per gram, respectively, had a definitely "off" odour, together with weak or stuck yolk. All other eggs were passed as being of acceptable quality, yet counts as high as 1,400,000,000 per gram were obtained (Table 6).

In a later series of tests, fresh eggs were exposed to infection as previously described, held for 1 week at 58° F., then at 40° F. for 7 weeks before being broken out. In this experiment, only the eggs exposed to the *Pseudomonas* cultures were found to contain significant numbers of bacteria (Table 7). Subsequent tests on the growth range of the various cultures used in inoculation experiments showed only the *Pseudomonas* species to be capable of strong growth at 40° F. or lower. The presence of the *Achromobacter* and *Flavobacterium* species in very large numbers in apparently normal eggs (Table 6) is strong presumptive evidence that the eggs in question had been stored at temperatures well above 40° F. for considerable periods before going into proper shell egg storage.

DETECTION OF HIGH COUNT "NORMAL" EGGS BY THEIR FLUORESCENCE

While it is now generally accepted that the majority of eggs as laid are free from micro-organisms, the possibility that eggs may carry large numbers of bacteria without any evident change in odour or appearance has been recognized (5, 14). In the Southwestern section of the United States it is not uncommon during wet weather in early spring to find such eggs in significant numbers (13). Since the majority of the bacteria isolated from such eggs are species of *Pseudomonas*, and since the members of this genus are known to produce substances fluorescing under ultra-violet light, the possibility of detecting such eggs at the time of breaking has been explored by some of the larger egg-breaking concerns there. It has been reported (13) that in one plant where special ultra-violet lamps replaced the ordinary illumination in the breaking room, it was possible, by rejection of eggs showing fluorescence, to reduce the counts on melange to one-fortieth of the previous count. While the majority of the cultures isolated in our laboratory were not *Pseudomonas* species, it seemed worth while determining the value of the ultra-violet lamp in the detection of these apparently normal high count eggs in Canada.

Through the courtesy of Swift and Company, Chicago, one of the special ultra-violet lamps from their Research Laboratories was made available for tests on storage eggs at Plant H. An assistant, whose knowledge of egg quality was well above average, was assigned to break out the eggs. As wide a selection as possible was obtained by picking a few eggs from each case as they were transferred to the shell egg buckets. Each egg was broken separately into a special black enamelled cup and checked for odour, appearance and fluorescence. If normal in odour and appearance, yet showing fluorescence, the degree of fluorescence was estimated and the egg transferred to a sterile screw-capped jar. It was then shaken vigorously to emulsify it, and a Burri slant prepared. The knife and cup were replaced each time a fluorescent egg or "reject" was encountered. In order to check on the possibility of high counts from non-fluorescent eggs, 69 eggs showing no fluorescence and 19 showing doubtful fluorescence were

examined bacteriologically. Burri slants were incubated at 70° to 80° F. (21° to 27° C.) for 3 days before being counted.

The results obtained from the examination of 240 eggs are summarized in Table 8. Although there is some correlation between count and degree of fluorescence, there are many discrepancies. If an egg showing 3 + or greater is regarded as definitely fluorescent, 31.3% of such eggs had counts under 2,000, 53% under 10,000, and 75% under 40,000 per gram. Thus if all eggs showing definite fluorescence were discarded it would mean the rejection of a considerable percentage which were otherwise acceptable.

On the other hand, the data show that high count eggs do not always show fluorescence. Results obtained in the analysis of 348 storage eggs in August, 1943 (6) showed only 2.3% with counts in excess of 40,000 per gram. Taking this as the maximum acceptable count, it will be seen that in the present studies only 8 of the 28 eggs in this group showed definite fluorescence as defined above. Among the remaining 20 eggs are two with counts of more than 10,000,000 and 20,000,000 per gram, respectively. While the elimination of those eggs showing strong fluorescence would help in reducing the count, it would not prevent the occasional acceptance of eggs with very high counts, while at the same time rejecting a number of acceptable eggs.

In our studies with cultures isolated from apparently normal eggs, definite fluorescence was noted on eggs experimentally infected with *Achromobacter* and *Flavobacterium* species as well as with *Pseudomonas* when held at 58 to 60° F. (Table 6). To determine whether there was any correlation between the type of organism and the degree of fluorescence of the naturally infected egg (Table 8), cultures isolated from high count eggs were identified as to genus. The results (Table 9) indicate no definite correlation. *Achromobacter* and *Flavobacterium* species were isolated from eggs showing medium to strong fluorescence, while 1 of the 3 eggs from which a *Pseudomonas* species was isolated showed little or no fluorescence. However, the bacterial contents of the eggs infected with *Pseudomonas* species were much lower than those generally encountered where *Achromobacter* or *Flavobacterium* species were found. It is of interest to record that although the *Pseudomonas* species were the only ones showing strong growth at 29° F. (-2° C.) within 2 weeks, all but one of the other cultures showed moderate growth at this temperature after 5 weeks, while all showed good growth at 40° F. (4° C.) after 1 week.

THE PRESENCE OF STREPTOCOCCUS FAECALIS IN EGG POWDER

In view of the assertion that *Streptococcus faecalis*, an organism commonly isolated from the intestinal contents of man and other animals, is one of the commonest species found in egg powder, two representative colonies were picked from plates poured from 38 Grade A and 12 Grade B carlot samples. These included powder from each of 8 drying plants. Of 96 such cultures studied in detail, only 3 proved to be *S. faecalis*. As had been found in 1943, the commonest type of organism appearing on plates of tryptone-glucose-extract-skimmilk agar incubated for 48 hours at 37° C. (98.6° F.) was a streptococcus, so far unidentified, which forms small amounts of acid but fails to curdle litmus milk at room temperature or 30° C. (86° F.).

DISCUSSION

The experience of the past summer suggests the need for revising our opinion regarding the sanitary significance of high direct microscopic counts in dried whole egg powder. Previously we would have been in entire agreement with the statement of Lepper, Bartram and Hillig (11) that, "In no instance did dried eggs show a microscopic count exceeding 10 million per gram when they were prepared from sound raw material. In all cases where these counts were exceeded, decomposed or rotten eggs had been incorporated in the product or the eggs had been subjected to conditions after breaking-out which permitted them to sour." For at least some of the high count samples examined here in 1944, we have reason to believe that this statement would not hold true. There was no temptation for a dryer to use sub-standard eggs, since the Special Products Board furnished graded eggs and maintained a resident inspector at the plant. Furthermore, the dryer was faced with a stiff financial penalty if his product failed to meet the bacteriological specifications. Consequently, dryers were very particular about the quality of eggs broken out.

Although the results obtained in 1944 indicate that some caution must be observed in interpreting high direct microscopic counts, it should not be concluded that such counts are of little value in controlling sanitation and plant practices. As will be seen from the data in Table 10, there have been several instances in which faulty practices such as inadequate cooling of melange were not reflected in the viable count or pH value of the powder, but were detected through the direct microscopic count. High microscopic counts due to the eggs themselves are largely, if not entirely, made up of rod forms; those due to faulty plant practices, on the other hand, are usually made up mainly of paired cocci, resembling the picture obtained in souring milk. This distinction has often proven to be of real value when the cause of a high count is being sought.

The direct microscopic count is particularly valuable in that it does not appear to be affected by conditions of drying and subsequent storage to the same degree as is the viable count. Plants vary greatly in the degree of bacterial destruction brought about by the drying process, as indicated by the data shown in Table 11. Without the direct microscopic count, some plants would be credited with doing a much better job than they are actually doing, while the converse would hold true for others. Studies intended to throw some light on the reasons for these differences in bacterial destruction between plants are under way during the 1945 drying season.

SUMMARY

As judged by plate counts, the bacteriological condition of Canadian dried eggs in 1944 was very satisfactory.

Unusually high direct microscopic counts were noted from May on. While a few of these were attributable to inadequate cooling of melange due to refrigeration failures, the majority were due to the inclusion of a small percentage of eggs which, while apparently normal in appearance and odour, yet contained enormous numbers of bacteria. Fluorescence under ultra-violet light was of limited value in the detection of such eggs.

While a high direct microscopic count cannot always be regarded as an indication of faulty plant practice, the method can yield information in this regard which is not always obtainable through the plate count or pH value.

ACKNOWLEDGMENTS

Grateful acknowledgment is made to Mr. N. Constabaris, Canadian Doughnut Co., Trenton, Ont., for assistance in obtaining cultures from high count eggs; to Mr. Howells Frechette, Chief, Division of Industrial Minerals, Department of Mines and Resources, Ottawa, for facilities and assistance in testing eggs for fluorescence; to Swift and Co., Chicago, for making available their special ultra-violet lamp; to Mr. D. A. Fletcher and other representatives of the Special Products Board, and to the drying plant operators, for their co-operation in various ways.

REFERENCES

1. AMERICAN PUBLIC HEALTH ASSOCIATION. Standard Methods for the Analysis of Dairy Products. 8th ed. New York, N.Y. 1941.
2. GORESLINE, H. E. and V. H. McFARLANE. Handling eggs for drying. U.S. Egg Poultry Magazine. 50 : 3; 116-119, 140-144. 1944.
3. GORESLINE, H. E. Private communication, November 1, 1944.
4. HAINES, R. B. and T. MORAN. Porosity of, and bacterial invasion through, the shell of the hen's egg. J. Hyg. 40 : 4; 453-461. 1940.
5. JENKINS, M. K. and N. HENDRICKSON. Accuracy in the commercial grading of opened eggs. U.S. Dept. Agr. Bull. 391. 1918.
6. JOHNS, C. K. The bacterial content of shell eggs. Food in Canada. 3 : 12; 15-16. 1943.
7. JOHNS, C. K. Few bacteria in Canadian eggs. Food in Canada. 4 : 4; 16. 1944.
8. JOHNS, C. K. The Burri slant technique in the food industries. Food in Canada. 4 : 3; 17-18. 1944.
9. JOHNS, C. K. Microbiological aspects of egg powder. Sci. Agr. 24 : 8; 373-382. 1944.
10. JOHNS, C. K. and H. L. BERARD. Direct microscopic method in bacteriological control of dried whole eggs. Food Res. 9 : 5; 396-399. 1944.
11. LEPPER, H. A., M. T. BARTRAM and F. HILLIG. Detection of decomposition in liquid, frozen and dried eggs. Jr. A.O.A.C. 27 : 204-223. 1944.
12. MALLMANN, W. L. and E. CHURCHILL. A rapid test for determining bacteria in liquid eggs. U.S. Egg Poultry Magazine. 48 : 406-407, 427-429. 1942.
13. MINK, L. D. Private communication, November 2, 1944.
14. PENNINGTON, M. E., M. K. JENKINS, E. Q. ST. JOHN and W. C. HICKS. Bacteriological and chemical study of commercial eggs in the producing districts of the Central West. U.S. Dept. Agr. Bull. 51. 1914.

TABLE 1.—MONTHLY ARITHMETICAL AVERAGES OF BACTERIA COUNTS FOR CANADIAN GRADE A DRIED WHOLE EGG POWDER, 1943-1944

Month	Plate count (thousands per gram)		Direct microscopic count (thousands per gram) 1944	Percentage over 2,000,000
	1943	1944		
January	84	27.5	130	0
February	409	82	250	0
March	160	86	321	0
April	120	58.4	267	0
May	80	75.5	1,785	17.1
June	139	68	1,652	25.5
July	90	115	4,642	37.2
August	130	112	3,522	48.9
September	94	119	3,998	47.7
October	102	101	4,436	62.5
November	681	143	4,595	42.5
December	376	131	1,810	33.3

TABLE 2.—BACTERIA COUNTS ON CONSECUTIVE CARLOT SAMPLES OF GRADE A POWDER FROM WESTERN CANADIAN PLANTS

Plant	Date analysed	Count per gram	
		Direct microscopic	Plate
A H-18	April 22	< 70,000	17,000
J- 2	May 3	< 70,000	9,800
J-12	May 13	< 70,000	12,000
J-19	May 24	22,000,000 Y	28,000
J-30	June 3	340,000	22,000
B H-10	April 15	70,000	18,000
H-24	May 1	150,000	9,500
J-12	May 13	290,000	10,000
J-24	May 29	2,700,000	4,900
K- 9	June 15	2,200,000	7,100
K-17	June 17	6 000,000 Y	36,000
K-23	June 23	590,000	12,000
C H-30	May 4	220,000	83,000
J- 5	May 8	1,300,000	44,000
J-10	May 15	510,000	45,000
J-18	May 25	4,400,000 Y	25,000
J-25	May 23	440,000	33,000
J-30	June 2	660,000	13,000
K- 5	June 7	70,000	37,000
D J- 1	May 3	220,000	6,800
J- 4	May 9	< 70,000	8,100
J-10	May 12	< 70,000	11,000
J-14	May 16	810,000	7,900
J-17	May 19	660,000	8,700
J-22	May 24	510,000	10,000
J-23	May 27	10,000,000 Y	2,300
J-26	May 27	340,000	5,300
E H-20	April 26	810,000	220,000
J- 4	May 9	1,300,000	530,000
J-15	May 16	4,100,000	740,000
J-27	May 31	2,700,000	37,000
K- 6	June 7	810,000	25,000
K-20	June 29	220,000	65,000

Y = high count due to Y organism.

TABLE 3.—BACTERIA COUNTS ON SPECIAL SAMPLES OF GRADE A POWDER FROM TWO WESTERN CANADIAN PLANTS, 1944

Plant	Time of sampling	Direct microscopic count	Plate count
A	Start of run, May 25	19,000,000 Y	8,600
	Finish of run, May 25	23,000,000 Y	23,000
	Start of run, May 26	18,000,000 Y	9,100
	Finish of run, May 26	140,000,000 Y	83,000
	Start of run, May 27	17,000,000 Y	10,000
	Finish of run, May 27	7,300,000 Y	88,000
C	Start of run, May 26	17,000,000 Y	8,300
	Finish of run, May 26	6,600,000 Y	38,000
	Start of run, May 27	21,000,000 Y	20,000
	Finish of run, May 27	8,400,000 Y	20,000
	Start of run, May 28	7,000,000 Y	10,000
	Finish of run, May 28	12,000,000 Y	11,000

Y = high count due to Y organism.
Average length of run = 21 hours.

TABLE 4.—COUNTS OBTAINED BY BURRI SLANT METHOD ON PAILS OF MELANGE BROKEN OUT WITH SPECIAL PRECAUTIONS.
PLANT E, MAY 29, 1944

Lot No.	Pail No.	Count per gram
2529	1	1,400,000
	2	< 2,000
	3	4,000
	4	10,000
	5	20,000
	6	320,000
2536	1	300,000
	2	22,000
	3	58,000
	4	10,000
	5	600,000
	6	4,000

TABLE 5.—COUNTS OBTAINED BY BURRI SLANT METHOD ON PAILS OF MELANGE BROKEN OUT WITH SPECIAL PRECAUTIONS. PLANT H, AUGUST 23-24, 1944

Lot No.	2172	3204	2167	2167	2167
Time of sampling	23rd a.m.	23rd p.m.	24th a.m.	24th a.m.	24th a.m.
Pail No.	Count per gram				
1	2,000	3,700,000	800,000	8,000	2,000
2	1,000	3,200,000	1,100,000	2,400,000	3,800,000
3	1,600,000	1,400,000	7,000	900,000	1,600,000
4	1,500,000	4,000,000	2,000,000	3,000,000	4,000
5	1,000	1,100,000	4,000,000	3,800,000	1,200,000
6	1,300,000	1,200,000	16,000	700,000	46,000

TABLE 6.—RESULTS OF EXAMINATION OF EGGS EXPOSED TO INFECTION WITH CULTURES OF BACTERIA ISOLATED FROM APPARENTLY NORMAL EGGS

Culture	Species	Storage conditions	Fluorescence	Plate count per gram
A	<i>Achromobacter</i>	4 weeks, 58-60° F.	+++	2,500,000,000
B 1	<i>Flavobacterium</i>	4 weeks, 58-60° F.	?	300,000,000
E	<i>Pseudomonas</i>	4 weeks, 58-60° F.	?	120,000
K	<i>Pseudomonas</i>	4 weeks, 58-60° F.	++++	260,000,000
N	<i>Achromobacter</i>	4 weeks, 58-60° F.	?	160,000,000
A	<i>Achromobacter</i>	5 weeks, 58-60° F.	?	2,800,000,000
B 1	<i>Flavobacterium</i>	5 weeks, 58-60° F.	+++	86,000,000
J	<i>Flavobacterium</i>	5 weeks, 58-60° F.	?	800,000,000
K 5	<i>Flavobacterium</i>	5 weeks, 58-60° F.	?	1,400,000,000
R	<i>Achromobacter</i>	5 weeks, 58-60° F.	++	84,000,000

TABLE 7.—RESULTS OF EXAMINATION OF EGGS EXPOSED TO INFECTION WITH CULTURES OF BACTERIA ISOLATED FROM APPARENTLY NORMAL EGGS*

Culture	Species	Appearance and odour	Fluorescence	Bacteria per gram
B 1 a	<i>Flavobacterium</i>	O.K.	—	8,000
b	<i>Flavobacterium</i>	O.K.	—	< 2,000
E a	<i>Pseudomonas</i>	White sl. green	+++++	720,000,000
b	<i>Pseudomonas</i>	O.K.	—	< 2,000
G a	<i>Pseudomonas</i>	White sl. green	++++	310,000,000
b	<i>Pseudomonas</i>	White sl. green	++++	430,000
J a	<i>Achromobacter</i>	O.K.	—	< 2,000
b	<i>Achromobacter</i>	O.K.	—	< 2,000
K a	<i>Pseudomonas</i>	White sl. green	++++	480,000,000
b	<i>Pseudomonas</i>	White sl. green	++++	120,000
N a	<i>Achromobacter</i>	O.K.	—	< 2,000
b	<i>Achromobacter</i>	O.K.	—	< 2,000
R a	<i>Achromobacter</i>	O.K.	—	< 2,000
b	<i>Achromobacter</i>	O.K.	—	< 2,000
Control a	—	O.K.	—	< 2,000
b	—	O.K.	—	< 2,000

* Eggs held for 1 week at 58° F., then for 7 weeks at 40° F. before being broken out.

TABLE 8.—CORRELATION BETWEEN FLUORESCENCE AND BACTERIAL CONTENT OF STORAGE EGGS BROKEN OUT NOVEMBER 24, 1944

Bacteria count per gram	No. of eggs	Degree of fluorescence						
		—	+	?	+	++	+++	++++
< 2,000	120	34	8	45	23	9	1	
2,000 – 10,000	69	22	4	19	17	7		
11,000 – 50,000	25	8	3	1	5	7		1
51,000 – 200,000	14	6	3	2	3			
201,000 – 1,000,000	5		1		2		2	
1,010,000 – 5,000,000	1						1	
> 5,000,000	6			1	1	2	2	
	240	70	19	68	51	25	6	1

TABLE 9.—RELATIONSHIP BETWEEN BACTERIA COUNT AND FLUORESCENCE OF APPARENTLY NORMAL EGGS AND THE CHARACTERISTICS OF THE ORGANISMS ISOLATED THEREFROM

Culture No.	Genus	Growth —2° C. in 2 weeks	Bacteria count per gram	Degree of fluorescence of	
				Egg*	Culture†
T 1	<i>Achromobacter</i>	—	>20,000,000	++	—
T 2	<i>Achromobacter</i>	—	>10,000,000	+	—
T 3	<i>Achromobacter</i>	—	280,000	?	—
T 12	<i>Achromobacter</i>	—	>10,000,000	+++++	—
T 18	<i>Achromobacter</i>	—	9,000,000	+++++	—
T 6	<i>Flavobacterium</i>	+	8,000,000	+++	—
T 123	<i>Flavobacterium</i>	—	10,000 000	+++	—
T 10	<i>Pseudomonas</i>	+++	450,000	+++++	+++
T 97	<i>Pseudomonas</i>	+++	66,000	?	+++
T 116	<i>Pseudomonas</i>	+++	240,000	+++++	+++

* Determined by U.-V. light at the moment of breaking.

† Determined by U.-V. light on 24-hour growth in Georgia & Poe's asparagine medium.

TABLE 10.—DATA ON SAMPLES WHERE HIGH COUNTS WERE BELIEVED TO BE DUE TO FAULTY PLANT PRACTICES

Plant	Carlot No.	pH Value	Plate count	Direct microscopic count
B	L-20	8.68	100,000	13,000,000
	L-25	8.65	240,000	92,000,000
C	K-26	8.70	100,000	20,000,000
	M-30	8.72	230,000	13,000,000
	O-25	8.54	2,000,000	520,000,000
F	M-11	7.82	64,000	150,000,000
	N-14	8.57	29,000	35,000,000
	P-24	8.58	39,000	18,000,000
G	M-14	8.67	790,000	15,000,000
	O-14	8.54	260,000	11,000,000
	O-20	8.61	500,000	18,000,000

TABLE 11.—EFFICIENCY OF BACTERIAL DESTRUCTION AS JUDGED BY RATIOS OF PLATE COUNTS TO DIRECT MICROSCOPIC COUNTS ON DRIED WHOLE EGGS

(October-December, 1944)

Plant	Carlot No.	Plate count per gram	Direct microscopic count per gram	Ratio
E	O- 9	390,000	2,900,000	1 : 7.4
	O-23	26,000	1,400,000	1 : 53.8
	O-31	380,000	2,200,000	1 : 5.8
	P- 9	1,000,000	2,000,000	1 : 2.0
	P-17	590,000	1,800,000	1 : 3.1
	P-25	340,000	1,100,000	1 : 3.2
	Q- 5	330,000	510,000	1 : 1.5
	Q-14	150,000	810,000	1 : 5.4
	Q-21	110,000	440,000	1 : 4.0
			Average	1 : 9.6
F	O- 9	27,000	7,900,000	1 : 292.6
	O-22	12,000	11,000,000	1 : 916.6
	O-30	13,000	5,700,000	1 : 438.5
	P- 9	24,000	12,000,000	1 : 500.0
	P-18	20,000	17,000,000	1 : 850.0
	P-24	39,000	18,000,000	1 : 461.5
	Q- 5	20,000	3,400,000	1 : 170.0
	Q-18	18,000	3,200,000	1 : 177.7
	Q-26	50,000	8,200,000	1 : 164.0
			Average	1 : 441.2

THE DIAGNOSIS OF SEX BY MEANS OF HETEROPYCNOSIS¹

STANLEY G. SMITH²

Science Service, Ottawa, Ont.

[Received for publication February 26, 1945]

The Basic Problem

In countries that have taken the appropriate statistics it is found that a gradual and progressive change occurs in the secondary sex ratio of man running from 104–107 ♂♂ : 100 ♀♀ at birth to a preponderance of females that approaches 2 : 1 at extreme senescence. Furthermore, by taking these post-uterine data together with the sex ratio obtaining among still births, premature births and abortuses, evidence is adduced by extrapolation pointing to a primary sex ratio, or that obtaining at conception, approaching 150 : 100. Expressed very roughly, then, the sex ratio changes between conception and extreme old age from 150 : 100 to 50 : 100. The conclusion that the change is due to a constitutional weakness of the male relative to the female is supported by a consideration of the influence of various environmental conditions (Crew, 4).

These facts pose two distinct problems: *first, what factors are concerned in the observed sexually selective mortality that operates against the male? second, what is the underlying cause of the initial inequality of the two types of zygotes?*

Hypotheses Regarding Differential Mortality

Three obvious factors have been suggested as contributing to differential mortality: (1) the operation of sex-linked genes that are disadvantageous, deleterious or lethal; (2) sex-limited defects and derangements; and (3) differences in the relative metabolic rates of males and females. Now since a similar preponderance of male live births holds for most domestic mammals, and since in all mammals it is the male that is the heterogametic sex, it is impossible, on the evidence presented by them, to decide whether the inherent weakness of the male results purely and simply from his maleness or whether it results from his heterogametic constitution.

Hypotheses Regarding Inequality of Sexes

Regarding the second problem, the numerical inequality of the two sexes at conception, various solutions have been advanced. Clearly, on the strength of the extrapolation mentioned above, the Y-containing sperm is successful in fertilization to an extent approaching, in man, about one and one-half times that of the X-containing sperm. One suggestion regarding this is that the Y-sperm is produced proportionately more often, but this appears unlikely from observations of meiosis in the human male. However, instances of excess X-sperm production are known in *Drosophila* (Morgan, Bridges and Sturtevant, 14) in which the male is likewise heterogametic. Another, no more attractive, involves selective fertilization controlled by the female. Yet another suggests that the Y-sperm should function more readily since its mass should be less than that of the X-sperm.

¹ Contribution No. 2351, from the Division of Entomology, Science Service, Dominion Department of Agriculture, Ottawa, Canada.

² Assistant Entomologist; presently stationed at, and Research Fellow in, McGill University, Montreal, Canada.

This theory, put forward by Morgan (13), has been more favourably received because of the claim (Parkes, 15) that a bimodal curve results from plotting the head size of human sperm. To these may be added the possibility that, in view of the greater amount of active chromatin carried by the X relative to the Y-chromosome and its consequently greater mutation potential, the X-sperm may be more subject to the occurrence of mutations deleterious to the functioning of the gamete. Other things being equal, the X-sperm would be under a temporal handicap in the race to accomplish fertilization.

The Natural Experiment

In birds, certain fishes, and butterflies and moths, unlike all other known animal organisms (with the possible exception of the Trichoptera (Klingstedt, 10)), it is the female that is heterogametic. With this cytogenetic peculiarity firmly established, it soon became evident that they constitute material for a natural experiment by which to evaluate some of the possible solutions to the above two main problems. In the first place it becomes possible to determine the parts played by genetic and other factors when mortality is differential. If it is the heterogametic sex, regardless of whether this is male or female, that dies off more readily, the cause must rest in its genetic constitution; if, on the other hand, it is the male sex that is less viable, regardless of whether it is heterogametic or homogametic, maleness, as such, must be held responsible. In the second place, since with homogametic males there can be no choice between sperm, any numerical inequality of the two sexes at conception must be the direct responsibility of the female; one type of egg must be produced or must function in excess of the other. Both the possibility of different rates in the movement of sperm and that of differential selectivity by the female, as advocated in the case of humans, are here immediately ruled out for the simple reason that only one type of sperm is formed. To test for and between differential production and differential functioning of ova, it becomes necessary to determine whether, in heterogametic females, the primary sex ratio is other than equality.

Practical considerations usually limit the diagnosis of sex to those stages in the life cycle after the formation of the definitive gonad (but see later). Only in the complete absence of mortality during the earlier stages can this value be taken as the primary sex ratio.

In the attempt to arrive at both the true primary sex ratio and the initial gametic proportions, birds, fishes and lepidopterans all have their own particular disadvantages. Birds normally have a relatively low reproductive rate; the cytological constitution of most fishes is unknown; and Lepidoptera in general suffer from extreme mortality before sex can be easily determined. Of the three, however, the Lepidoptera are by far the most easily manageable and readily offer themselves in numbers upon which statistical reliance can be placed. Furthermore, in their diversity of egg-laying habits, they allow, by the selection of technically suitable species, the determination, not only of percentage mortality, but also the sequence in which viable and non-viable eggs are laid. Finally, as a result of the mechanics of egg-production in insects, the possibility of differential functioning can be tested and, if found inoperative, the degree of differential

production can be evaluated. The chief limitation, until now, has been the gap created by the delay in sex-differentiation; the greater the gap, the greater the part mortality can play, if differential, in distorting the sex ratio. As will be shown, we now have a method of narrowing the gap and, by the appropriate selection and classification of material, of closing it completely.

The Method of Approach

It is a well-known characteristic of sex chromosomes that in the heterogametic sex they often retain their staining capacity throughout the division cycle, while the autosomes, along with the sex chromosomes in the homogametic sex, are non-stainable during the resting stage. It should therefore be possible to use this phenomenon of heteropycnosis in the diagnosis of sex at stages prior to that at which anatomical differences are developed. Other cytological criteria are theoretically available but, if the sex chromosomes should display heteropycnosis in somatic cells, attention can then be confined to the resting nuclei, leaving the observer independent of numerical or size differences and angle of vision.

Application of Method and Results

The first step was to test for somatic heteropycnosis in lepidopterous larvae in which sex could be predetermined by external examination. The species selected for this purpose was *Archips fumiferana*, the spruce budworm, which for the past few years has again been occurring in extreme outbreak proportions over a large area of northeastern North America. In this species the sex can be determined by simple observation as the gonads of the male are clearly visible through the integument of the fourth and later instars. Temporary aceto-carmin slides and permanent Feulgen "squash" preparations (Smith, 18) made from the intestine showed deeply



FIGURE 1.

staining bodies in the resting nuclei of each of 17 female larvae studied, while they were absent from all the 12 males examined. These heteropycnotic bodies, restricted to the resting nuclei of females, are obviously the sex chromosomes and may therefore be used in the diagnosis of sex.

The method, slightly modified, was then applied to 399 freshly eclosed progeny of eight budworm pairs collected *in copula* from the wild. The modification facilitated the handling of the small larvae in the large numbers being dealt with. It consisted in fixing, embedding and sectioning families en masse rather than making individual preparations³. Also it was found more convenient to examine the relatively enormous cells of the silk glands (see Figure 1) since their use did away with the necessity of using the oil immersion objective. The results are tabulated below:

Family number	Total eggs laid	Total eggs unhatched	Percentage mortality	Heteropycnosis		Sex ratio
				Without	With	
8	53	0	0	25	28	♂ ^a ♀ 89 : 100
7	64	2	3	28	34	82 : 100
10	90	8	9	35	47	74 : 100
6	49	8	16	18	19	95 : 100
13	98	19	19	35	37	95 : 100
1	34	9	26	5	20	25 : 100
21	67	25	37	22	16	137 : 100
14	83	53	64	5	25	20 : 100
	538	124	23 Expected	173* 199.5	226* 199.5	76 : 100

$$X^2 = 7.04, P = ca .01$$

* The discrepancy between the number of larvae hatched and the number scored for heteropycnosis is due solely to the fact that the last 15 larvae to hatch were not embedded due to pressure of work.

^a I am indebted to Dr. W. O. Rothwell, Temiskaming Hospital, for providing the facilities for embedding the material described herein.

There is no intention of analysing these results to determine whether the primary sex ratio in Lepidoptera, as represented by *Archips fumiferana*, is other than equality. They have been presented, to show, first, that the phenomenon of somatic heteropycnosis, when the property of a species, can be used in the early diagnosis of sex and, secondly, that direct evidence can be obtained regarding the primary sex ratio and the effect on it of differential mortality. Of course, the present results require considerable amplification.

Limitations of Method

To what extent the method can be applied to other organisms is at present unknown for, although much work has been done on heteropycnosis since it was first noted by Henking (7) in 1891, remarkably few generalizations can be made concerning it. Thus almost 40 years after Henking's original observations Schrader (16, p. 8) had perforce to qualify the statement that "It is of interest to observe that this special behaviour of the sex chromosomes is not manifested prior to the spermatogonial stages," as

follows—"However, it must not be forgotten that researches touching on the sex chromosomes in somatic cells are small in number and generalization is not justified."

There are certainly many circumstances that curtail the general use of the method. For example, in the only extensive survey published to date, Geitler (6) found, in the Heteroptera, that somatic heteropycnosis is not the exclusive property of the sex chromosomes of one sex in all species. This is in agreement with Kaufmann's (8) observations on *Drosophila melanogaster* where the sex chromosomes in the somatic cells of both the male and the female exhibit heteropycnosis, and is supported by the writer's (unpub.) survey of Coleoptera in which both sexes of certain species are found to be devoid of this property. In the Acrididae the sex chromosomes fail to display heteropycnosis until the spermatogonial divisions (Mohr, 11, 12) but later, during the meiotic prophase, certain autosomes or parts of autosomes (Carothers, 2) may show a similar but less intense reaction. Again heteropycnosis is normally the property of odd supernumerary chromosomes at meiosis (Wilson, 19) but fails to express itself when the supernumerary is present in duplicate (Carroll, 3). Conditions in the Lepidoptera are variable. Thus both Seiler (17) and Dederer (5), working on *Phragmatobia* and *Philosamia*, respectively, report that during meiosis the sex chromosomes of the female are indistinguishable from the autosomes. Kawaguchi (9), however, finds that they are heteropycnotic during the meiotic prophase in some species but not in others. In *Archips fumiferana* no indication of heteropycnosis has been found during either oogenesis or spermatogenesis (unpub. data) even though its occurrence in somatic tissues of the female is beyond dispute.

Advantages of Method

In conclusion, it might be pointed out that, although there appear to be technical limitations to the use of the method due to the apparent need for specialized equipment, it is possible to dispense with sectioning by using aceto-carmine staining. However, the practice of mass embedding and sectioning is less time-consuming and less tedious. The alternative method of diagnosing sex by dissecting for primordial gonads is unfortunately, even where possible, likely to leave a considerable unclassifiable residue, whereas using heteropycnosis there is none. Thus Brandt (1) found it impossible to classify more than 537 out of 717 first instars of *Lymantria monacha* on the basis of the morphology of the primordial gonads. With a surplus of only 4.6 females per hundred larvae it would obviously be worthwhile in future to attempt to sex any residual larvae by means of the aceto-carmine technique. This involves nothing more than dissecting the silk glands in a drop of aceto-carmine and examining them after a minute or so under a microscope capable of giving a magnification of only about $\times 300$.

SUMMARY

The facts and hypotheses concerning the human sex ratio are briefly reviewed. The limitations imposed by high mortality on the use of the Lepidoptera as a "natural experiment" by which certain of the hypotheses may be critically appraised are discussed and the possibility is demonstrated of using somatic heteropycnosis as diagnostic of sex prior to sexual differentiation and before differential mortality can distort the primary sex ratio.

REFERENCES

1. BRANDT, H. Untersuchungen über die Änderung des Geschlechtsverhältnisses bei der Nonne (*Lymantria monacha* L.) und ihr Ursachen. Zeits. Angew. Ent. 24 : 1; 87-94. 1937.
2. CAROTHERS, E. E. The mendelian ratio in relation to certain orthopteran chromosomes. J. Morph. 24 : 487-511. 1913.
3. CARROLL, M. An extra dyad and an extra tetrad in the spermatogenesis of *Camnula pellucida* (Orthoptera); etc. J. Morph. 34 : 375-455. 1920.
4. CREW, F. A. E. The sex ratio. Brit. Assoc. Rep., Section D—Zoology : 95-114. 1937.
5. DEDERER, P. H. Oogenesis in *Philosamia cynthia*. J. Morph. 26 : 1; 1-41. 1915.
6. GEITLER, L. Das Heterochromatin der Geschlechts-chromosomen bei Heteropteren. Chromosoma 1 : 2; 197-229. 1939.
7. HENKING, H. Untersuchungen über die ersten Entwicklungsvorgänge in den Eiern der Insekten II, etc. Zeits. wiss. Zool. 51 : 685-736. (Cited by Schrader, 1928). 1891.
8. KAUFMANN, B. P. Somatic mitoses of *Drosophila melanogaster*. J. Morph. 56 : 1; 125-155. 1934.
9. KAWAGUCHI, E. Die Heteropyknose der Geschlechts-chromosomen bei Lepidopteren. Cytologia 4 : 4; 339-354. 1933.
10. KLINGSTEDT, H. Digamete beim Weibchen Trichoptere *Limnophilus decipiens* Kol. Act. Zool. Fenn. 10 : 1-69. 1931.
11. MOHR, O. L. Sind die Heterochromosomen wahre Chromosomen? etc. Arch. f. Zellforsch. 14 : 151-176. 1915.
12. MOHR, O. L. Studien über die Chromatinreifung der männlichen Geschlechtszellen bei *Locusta viridissima*. Arch. Biol. 29 : 579-752. 1916.
13. MORGAN, T. H. The physical basis of heredity. J. B. Lippincott Co. 1919.
14. MORGAN, T. H., C. B. BRIDGES, and A. H. STURTEVANT. The genetics of *Drosophila*. Bibliogr. Genet. 2 : 1-262. 1925.
15. PARKES, A. S. Dimorphism of Spermatozoa. Q.J. Micr. Sci. 67 : 617-625. 1923.
16. SCHRADER, F. The sex chromosomes. Berlin. 1928.
17. SEILER, J. Das Verhalten der Geschlechtschromosomen bei Lepidopteren, etc. Arch. f. Zellforsch. 13 : 159-269. 1914.
18. SMITH, S. G. Techniques for the study of insect chromosomes. Can. Ento. 75 : 2; 21-34. 1943.
19. WILSON, E. B. Note on the chromosome groups of *Metapodius* and *Banasa*. Biol. Bull. 12 : 5; 303-313. 1907.

NUMBER OF GENERATIONS OF *LYGUS HESPERUS* KNT. AND
L. ELISUS VAN D. IN ALBERTA¹

[Received for publication February 26, 1945]

R. W. SALT²*Dominion Entomological Laboratory, Lethbridge, Alberta*

Several papers dealing with the legume bugs, *Lygus hesperus* Knt. and *L. elisus* Van D., have recently appeared in entomological literature. In addition there are some previous articles concerning *Lygus pratensis* L. which should properly include *L. hesperus* and *L. elisus*, due to a failure to distinguish specific differences. The two first-mentioned species are so intermingled in many areas and have such similar habits that for most practical purposes they may be studied as a single species, and several workers have done so. In view of the considerable amount of study which has been devoted to these pests it is remarkable that a particular error should crop up again and again, not merely by quotation but in independent research. Reference is made to the number of generations of *Lygus* per year, particularly in the northwest United States.

Several writers state that they have endeavoured to rear *Lygus* through successive generations, but the best that seems to have been accomplished so far is one complete generation. Most of the data are composite records from the rearing of the various stages. From these the life cycle has been variously reported as requiring 20 to 30 days under favourable conditions, but running as high as 46 days. Some authors have divided this period into the length of the active season, getting from 3 to 7 generations (1, 2, 4). Although this may seem a logical method of determining the number of generations, it proves to be a very inaccurate one. It fails to take into consideration the fact that the time required for different individuals to complete a generation varies in accordance with a number of complex ecological and nutritional factors, and any attempt to strike an average for use in calculations such as the above only increases the error. As no one has yet been successful in rearing successive generations of *Lygus elisus* or *L. hesperus*, the next best resort is to determine the number of generations from fluctuations in the numbers of each stage of the insect, in a specific natural environment and throughout a complete season.

During the summer of 1932 the writer made such a study of *Lygus hesperus* and *L. elisus* by making periodic collections in an alfalfa seed field located on the Dominion Experimental Farm at Lethbridge, Alberta. The field remained uncut during the entire period. Collections were taken approximately once a week until the first appearance of nymphs and twice a week thereafter. During the early part of the season, when adults were scarce, 1,000 sweeps with a 14-inch net were taken as a unit collection, but

¹ Contribution No. 2357, Division of Entomology, Science Service, Department of Agriculture Ottawa, Canada.

² Agricultural Scientist.

later the units were cut to 100 sweeps. The results are contained in Figure 1, each instar being shown separately. Taking into consideration the variation in collecting conditions during the summer, and the fact that two species are involved, the population curves shown in the figure are quite uniform.

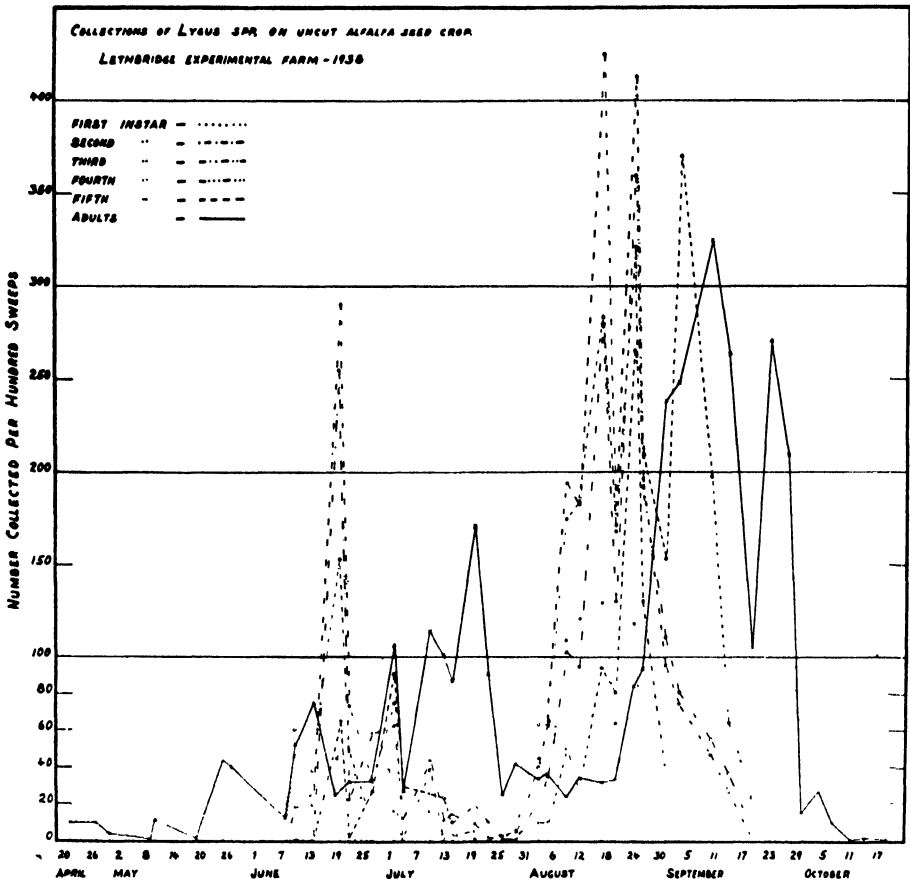


FIGURE 1. Collection of *Lygus* spp. on uncut alfalfa seed crop at Dominion Experimental Farm, Lethbridge, Alberta, 1936.

In order to determine the number of generations it is necessary to consider the various curves one at a time. The adult curve stands out distinctly from those of the nymphal instars and shows a peak during the middle of July following a previous peak in the nymphal population. A secondary peak on September 23, following a drop on September 19, could not possibly be interpreted as another generation as the time is much too short, especially so late in the season. In addition, the low nymphal population at that time precludes such an idea, and if further proof be needed it is found in the fact that egg development in the adult females ceases before that date. Turning next to the five nymphal instars, if the population curve of each is carefully followed in the figure, it will be seen that

each instar follows in point of time the preceding instar. This is especially clear in the part of the curves subsequent to August 1, where there is decidedly but one generation. The earlier build-up of nymphs during June is not so clear, but that only one generation is involved can be easily shown as follows. The second, third and fourth instars were at a peak on June 20. A secondary peak on July 2 not only leaves insufficient time for another complete generation to have developed but it is composed of later stages than the first peak, namely, fourth- and fifth-instar nymphs and adults. The secondary variations shown in the curves are due mainly to differences in weather conditions, but even these are not sufficient to obliterate proof of the existence of only two generations of *Lygus* in this area. It is entirely possible, of course, that an occasional individual developed sufficiently in advance of the remainder to go through three or even more generations, but the low ebb of nymphs on and around July 26 makes it reasonably certain that the number of such individuals was minute.

More than two generations may, of course, occur farther south. However, Shull (3) published data similar to that given in the figure, listing the numbers of *Lygus* collected in an alfalfa field and a clover field in southern Idaho from April 27 to August 18, 1931. Three sets of figures are listed for each field—the number of nymphs, the numbers of adults, and a total of the two. The totals are also presented graphically. On the basis of these data Shull makes the statement, "There are four generations in southern Idaho each year as shown by the counts from alfalfa and clover sweepings in 1931 (Table XVI, Fig. 1, D)". A glance at the table shows two definite peaks of nymphal abundance, each indicating a clear-cut generation. The author, however, adds the nymphal figures to the adult figures and gets four peaks of abundance, concluding that there are four generations per year. Strangely enough, his first generation reached a peak on May 15, although the first nymphs of the season did not appear until May 21. Shull's data, therefore, give evidence of only two generations between April 27 and August 18, 1931. It is unfortunate that he did not carry his observations to a later date, for there may have been time for a third generation subsequent to August 18. It can be definitely said, however, that on the basis of Shull's data there are at least two, possibly three, but not four generations of *Lygus* in southern Idaho.

DISCUSSION

Two errors concerning the determination of the number of generations undergone by insects during a year are pointed out. Although specifically referring to *Lygus hesperus* and *L. elisus*, these comments undoubtedly apply in many other cases:

1. The practice of calculating the number of generations per year from the length of the total season and the length of one generation is inaccurate.

Variations in individual insects, combined with variations in environment throughout a field and throughout a season, do not allow the use of such simplified mathematics based on averages.

2. In determining the number of generations per year from population curves, each stage and instar should be studied as a separate entity. The bulking of population figures of various stages and instars leads to inaccurate conclusions.

REFERENCES

1. CROSBY, C. R., and M. D. LEONARD. The tarnished plant bug. New York (Cornell) Agr. Exp. Sta. Bull. 346. 1914.
2. MCGREGOR, E. A. *Lygus elisus*: A pest of the cotton regions in Arizona and California. U.S. D. A. Tech. Bull. 4. 1927.
3. SHULL, W. E. An investigation of the *Lygus* species which are pests of beans (Hemiptera, Miridae). Idaho Agr. Exp. Sta. Res. Bull. 11. 1933.
4. SORENSON, C. J. *Lygus* bugs in relation to alfalfa seed production. Utah Agr. Exp. Sta. Bull. 284. 1939.

A CONTRIBUTION TO THE KNOWLEDGE OF THE ACRIDIDAE OF ALBERTA¹

R. M. WHITE² AND P. J. G. ROCK³

Dominion Entomological Laboratory, Lethbridge, Alberta

[Received for publication February 26, 1945]

Since the publication of *Orthoptera of Alberta*, by Morgan Hebard in 1930 many new distributional records of Acrididae have been obtained in this province. During the current grasshopper outbreak, which started in 1930, the authors, while making surveys of grasshopper abundance, have covered much of the agricultural area of the province. Considerable collecting of all species has been done, particularly since 1936, and it has been possible to add materially to past records. The northwestern limits of distribution of a number of plains species and the southeastern limits of distribution of a number of boreal species are more clearly defined than they were in 1930. Few additional records have been secured from many of the less accessible and non-agricultural areas and, though occasional collecting was done in the mountainous regions, the information regarding the forms inhabiting those areas is still far from complete. The distribution of the spring forms of acridids is better understood than was the case in 1930 but it still leaves much to be desired. Supplementary notes will have to be published as more data are assembled.

Since material was collected from over 2500 localities, the authors, in order to avoid cumbersome lists of locations, have divided the province into ecological areas following the method used by Strickland (7), see Figure 1. Some alterations have been made in the boundaries, and the numbering, of Strickland's ecological areas to make them more applicable to orthopteroid distribution.

DESCRIPTION OF ECOLOGICAL AREAS

A. TRANSITION ZONE

1. Southern Prairie (Milk River Valley and ridge to the south)
Vegetation:—Short grass; *Artemisia* and greasewood.
Soil:—Brown.
Remarks:—This area is a northern extension of the Upper Sonoran or Upper Austral Zone. It is devoted chiefly to ranching except in the district around Coutts where there is considerable farming.
2. Cypress Hills
Vegetation:—About 50% forested—lodge-pole pine, spruce and poplar, long grass.
Elevation:—Up to 4500 feet. Summit of hills never glaciated.
Soil:—Very dark brown to black.
Remarks:—Flora and fauna quite similar to Waterton Lakes (16) area.

¹ Contribution No. 2349, Division of Entomology, Science Service, Department of Agriculture, Ottawa, Canada.

² Assistant Entomologist.

³ Agricultural Assistant.



FIG. 1
ECOLOGICAL AREAS

FIGURE 1

3. Southern Prairie (Manyberries-Bassano-Altario)

Vegetation:—Short grass. Some poplars and willows in river bottoms. Cactus and sage in drier locations. Irrigated areas around Brooks which support a variety of crops, chiefly grain; much abandoned land, that more recently abandoned grown up to Russian thistle and tumbling mustard. Considerable areas of blow-out soil. Eroded areas adjacent to river bottoms. Some alkali sloughs and lakes.

Soil:—Brown.

4. Southern Prairie and Southern Extension of Northern Prairie (Woolford-Calgary-Hussar)

Vegetation:—Short to intermediate grass, occasional groves of willow and poplars. Crops, chiefly wheat.

Soil:—Brown to dark brown. Some eroded land along rivers; some alkali sloughs.

5. Northern Prairie, West (Crossfield-Halkirk)

Vegetation:—Intermediate grass; poplars, willows. Crops chiefly wheat.

Soil:—Dark brown, ranging from loam to very heavy clay or "gumbo."

6. Northern Extension of Southern Prairie (Sunnynook-Castor)

Vegetation:—Short to medium tall grass; a few trees along creeks and some alkali sloughs.

Soil:—Brown.

Remarks:—Marginal area for grain growing; large amount of abandoned land.

B. INTERMEDIATE BETWEEN TRANSITION AND CANADIAN ZONES

7. Parkland, East (Provost-Vermilion)

Vegetation:—Short to long grass. About 30% wooded with aspen poplar and willow groves. Crops, grain and hay.

Soil:—Dark brown to black.

8. Parkland, West (Didsbury-Vegreville)

Vegetation:—Originally about 50% wooded with aspen and willows, area now 75% cleared. Crops, grain and hay.

Soil:—Black.

C. CANADIAN ZONE

9. Poplar, West (Rocky Mountain House-Lac la Biche)

Vegetation:—Long grass. Originally balsam poplar, aspen, willow and some spruce; less than 50% cleared. Crops, mostly oats.

Soil:—Black to grey-wooded in North.

10. Poplar, East (St. Paul des Metis)

Vegetation:—Fall grass. Originally balsam poplar, aspen, willow with considerable local stands of spruce and pine; about 40% cleared. Crops, wheat and oats.

Soil:—Black, some muskeg.

11. Mixed Forest with Eastern and Sub-arctic Intrusions

Vegetation:—Largely forested with aspen, balsam poplar, spruce, jack pine, balsam fir, tamarack, willow, birch and alder.

Soil:—Grey-wooded, with extensive areas of sand.

Remarks:—No collections of Orthoptera have been made in this area.

12. Mixed Forest, with Cordilleran (Rocky Mountain) Intrusions

Vegetation:—Similar to No. 11. Many lakes and large areas of muskeg. A little cultivation in the south. Crops, chiefly oats.

Soil:—Gray-wooded.

13. Mixed Forest and Parkland (Peace River District)

Vegetation:—Large areas of forest interspersed with long grass open plains. Crops, chiefly grain.

Soil:—About 10-15% black loam, remainder gray-wooded with some muskeg.

D. FOOTHILLS ZONE

14. Foothills, Northern (Rocky Mountain House-Grand Prairie)

Vegetation:—Intermediate between that of Rocky Mountains and the mixed forest of northern Alberta. Much of this area is incompletely surveyed. In the western half some grain is produced.

Soil:—Gray-wooded; believed to be quite variable.

15. Foothills, Southern (Cowley to Rocky Mountain House)

Vegetation:—Aspen, spruce, lodge-pole pine, willow with mixed grasses and open prairie to southward.

Soil:—Gray-wooded in northern portion, dark brown to black in south.

Remarks:—This area is probably the most uniform of all areas.

E. MOUNTAIN ZONE

According to Strickland (7) "Vegetation:—This naturally varies greatly with the altitude of the montane, submontane, subalpine and alpine territory, also with topography, rock and soil. Montane territory is dominated by lodge-pole pine and white spruce. Douglas fir is locally abundant. Subalpine territory is characterized by Engelmann spruce, alpine fir, and other conifers, as well as by mountain heaths.

"From Area 18 to Area 21 (Area 16 to Area 19 in Fig. No. 1) there is a gradual and irregular replacement of southern and western species by certain boreal and arctic species."

16. Southern Rocky Mountains (Waterton-Blairmore)

Vegetation:—"Strong intrusions of southern and western species. These extend to about the northern limits of the area."

Soil:—The composition of the mountains in this area changes from largely igneous rock in the south to a high percentage of limestone in the north.

17. Central Rocky Mountains (Crow's Nest Pass-Lake Louise)

Vegetation:—Typical for that of Area 16 with a few southern and arctic intrusions.

Soil:—Variable in texture; all gray-wooded.

18. North Central Rocky Mountains (Banff Park, North)

Vegetation:—Similar to that of Area No. 17. Among the grasses are several which appear to be typical of the Labrador flora.

Soil:—Similar to that of Area No. 17.

Remarks:—Little collecting of Orthoptera has been done in this area.

19. North Rocky Mountains (Jasper National Park)

Vegetation:—As in Nos. 17 and 18 but with strong intrusions of arctic and boreal species.

Soil:—As in No. 18.

DISTRIBUTION OF SPECIES

Each species is recorded in the following manner:

1. The numbers of the various ecological areas from which it has been taken.
2. A list of the localities from which it has been previously recorded in the various publications by Hebard or by Tinkham (8).
3. The names of the towns comprising the north or northwestern limits of distribution in the cases of the plains species, or southeastern limits in the cases of the boreal species.
4. Notes of interest in connection with the species.

For example:

Ageneotettix deorum deorum (Scud.)

1, 3, 4, 5, 6, 7. Previous records are from Lethbridge, Coaldale, Taber, Medicine Hat, Steveston and Comrey. Alliance and Carstairs are the northern limits of distribution.

This species is fairly common in the southern portion of the province but is relatively scarce towards the northern limits of its distribution.

The numbers 1, 3, 4, 5, 6, 7, refer to the ecological areas from which these species has been collected. The remainder of the data are self-explanatory.

Mermeria maculipennis macclungi Rehn.

New record.

Reared from fifth instar nymphs collected at the mouth of the Lost River and in Blacktail Coulee at Onefour, one mile north of the Montana boundary. Five nymphs collected July 16, 1940. One adult emerged Aug. 1, 1940 (White & Rock). The species was present in clumps of *Calamovilfa longifolia* (Hook) in small numbers in sheltered places on the north banks of coulees.

Previous northern records from Montana are: Brinkman, July 25, 1935 (Shotwell and White), Billings, July 30, 1910 and Columbus, Sept. 1, 1924 (N. Criddle).

Acrolophitus hirtipes (Say)

1, 2, 3, 4. Previous records are Medicine Hat, Lethbridge and Macleod. Gleichen is the most northerly record.

This rather uncommon species is usually found on the brows of the banks of river valleys.

Opeia obscura (Scud.)

1, 2. This species was first taken by Tinkham at the Higdon Ranch, Comrey, in 1938. Further series were secured from Coutts, the Milk River Valley and Manyberries in 1939 and 1940.

A specimen in the collection was taken at Willow Bunch, Sask., Sept. 25, 1931 (G. F. Manson).

Amphilornus coloradus (Thos.)

1 to 9. Previous records are Manyberries, Walsh, Steeveville, Taber, Minda, Comrey and Lethbridge. (Minda was formerly a post office 5 miles N.E. of Manyberries.)

Northern records are Rochester and Wainwright.

This species is one of our most common range grasshoppers in southern Alberta. Towards its northern limits of distribution in the park belt it is quite scarce and is confined largely to grassy knolls.

Eritettix simplex tricarinatus (Thos.)

1. New record for Canada (Det. A. B. Gurney.)

This insect was taken in the Blacktail Coulee, at Onefour, July 15, 1940 (White & Rock). Hebard (2) gives Bozeman, Mont., as the nearest point at which this species was taken previously.

Philibostroma quadrimaculatum (Thos.)

1, 3, 4, 5, 6 and 17. Previous records are from Banff, Calgary, Lethbridge, Bow Island, Medicine Hat, Walsh and Comrey.

Banff and Wayne are northern records.

Cordillacris occipitalis cinerea (Bruner)

1, 3 to 7. Previous records are Lethbridge, Manyberries and Comrey. Ribstone, Amisk, Scapa and Morrin are northwestern records of distribution.

This species is confined largely to sand areas, river valleys and eroded areas.

Cordillacris crenulata (Bruner)

1. New record for Canada. (Det. by R. M. White, by comparison with specimen from Wyoming det. by Morgan Hebard.)

Taken in the valley of the Lost River, Onefour, July 15, 1941 (White).

Orphulella pelidna (Burm.)

1, 3 and 6. This species was first collected by Criddle at Orion in 1924 and reported by Hebard (6). It was again reported from Irvine, Cereal and Finnegan by Gurney (9). The writers have taken it, from a number of localities, in coarse grass at the edges of marshes and alkaline sloughs and springs. The species is quite localized in its habitat in Alberta.

Northwestern records are Coutts, Dorothy and Cereal.

Chloealtis conspersa Harris

1, 3, 4, 5, 7, 8, 9, 12, 13, 14, 16 and 17. Previous records are Crow's Nest Pass, Frank, Banff, Athabasca and Comrey.

The southern limits of distribution of this species are Cowley and Comrey. The latter record is only ten miles from the Montana border so the species should be present in the Sweet Grass Hills of that state.

A fully macropterous female was collected along the Smoky River near Debolt in Area 13 in 1938, while a male was taken at Fenn in 1939 (Rock).

Neopodismopsis abdominalis (Thos.)

2, 4 to 19. Previous records are Coleman, Fort Macleod, Lethbridge, Banff, Nordegg, Greencourt, Cold Lake, Cypress, Blairmore and Crow's Nest Pass.

This handsome species is quite widely distributed in the park belt. In the prairie section it is quite scarce and is usually confined to patches of *Symphoricarpos* along river bottoms or on hillsides.

Chorthippus longicornis (Latr.)

1 to 19, except 11. This species has previously been recorded from Coleman, Macleod, Fort Macleod, Blairmore, Cypress, Comrey, Banff, Tofield, Edmonton, Ponoka, Red Deer, Greencourt, Halcourt, Cold Lake and Grande Prairie.

It is the most common of the species that occur in the park belt. In the plains section it is confined largely to marshes or to clumps of *Symphoricarpos* along streams or in wooded hills.

The series shows a wide variation in the length of the organs of flight. Females range from brachypterous to macropterous. A few fully macropterous males are present but in the majority the tegmina extend only to the tip of the supra-anal plate or just beyond the tip of the abdomen at most.

Aeropedellus clavatus (Thos.)

1 to 19, except 11 and 18. Previous records are from Banff, Jasper, Fort Macleod, Lethbridge, Chin, Manyberries, Medicine Hat, Cypress and Comrey.

This species has probably the widest distribution of the acridids that occur in Alberta.

Bruneria brunnea (Thos.)

1 to 8, 10, 15, 16, 17, 19. Previous records are from Cypress, Comrey, Chin, Lethbridge, Kipp, Fort Macleod, Pincher, Coleman, Frank, Blairmore, Crow's Nest Pass, Banff and Jasper.

Jasper, Delbourne, Heisler and Myrnam are the northern records.

This is a moderately common species in areas of short dry grass.

Psoloessa delicatula delicatula Scud.

1, 3 to 7, 15 and 16. Previous records are Calgary, Macleod, Lethbridge and Comrey.

Lavoy is the most northern record. The species is a spring form and its distribution probably extends considerably north and west of this point.

Adults of this species are fairly common from May until July.

Ageneotettix deorum deorum (Scud.)

1, 3 to 7. Previous records are from Steveville, Lethbridge, Chin, Taber, Medicine Hat and Comrey.

Alliance and Carstairs are northern points of distribution.

This species is fairly common in the southern portions of the province but is relatively scarce towards the northern limits of its distribution.

Drepanopterna femoratum (Scud.)

1. This species was first collected at the Higdon Ranch, Comrey, by Tinkham in 1938. Further series were secured in 1939 and 1940 along the Milk and Lost rivers from Onefour to the Higdon Ranch (about 12 miles west of Comrey).

Aulocara elliotti (Thos.)

1 to 8, 15 and 16. Previous records are from Steeveville, Macleod, Lethbridge, Chin, Taber, Manyberries, Comrey and Medicine Hat.

Cochrane, Alix and Lavoy are northwestern records.

This is economically the most important species of the grasshoppers affecting the ranges in Alberta.

Stethophyma gracile (Scud.)

8, 9, 10, 12, 13, 14. Previous records are Cold Lake, Edmonton, Greencourt and Coronado.

Dundre, Delbourne and Strome are southern records.

This insect is quite local in its distribution as it is nearly always found in sedgy meadows, grassy swamps and occasionally in muskegs.

Stethophyma lineatum (Scud.)

7, 8, 9, 10, 13, 14. Cold Lake is the only previous record. Czar and Sundre are the southernmost records of the discontinuous distribution of this species.

This insect is usually found in the same habitat and in company with *S. gracile*.

Arphia conspersa Scud.

1 to 19, except 11. Previous records are Lethbridge, Calgary, Banff, Nordegg, Cold Lake, Wabamun, Grande Prairie, Peace River and Fort Vermilion.

This is the most common, and widely distributed spring form.

The wing discs are pink in all specimens except those from the vicinity of Jasper. There, only specimens with yellow to orange-yellow wings have been found. Yellow-winged specimens have been reported, by Hebard, from Banff, Nordegg and Wabamun.

Four females are light brown in colour.

Arphia pseudonietana pseudonietana (Thos.)

1, 3 to 9, and 17. Previously recorded from Banff, Calgary, Gull Lake, Medicine Hat, Walsh and Comrey.

Gull Lake and McLaughlin are northern records.

This handsome species is present in small numbers in the grasslands of Alberta. In two males and five females the disc of the pronotum, and the caudal portion of the occiput, is buffy, in sharp contrast to the darker parts of the insect.

Chortophaga viridifasciata (De Geer)

4 and 5. Previous record—Lethbridge.

Erskine is the most northern distributional record.

This spring form, which is frequently found in sandy soil in the river bottoms, appears to be quite localized in its distribution. It has been taken from only sixteen localities in these two areas.

Of the 34 males, 33 are brown and one is green with brown tegmina: of the 23 females, 20 are green, 2 are brown and one is green with brown tegmina. All specimens have yellow wing discs.

Encoptolophus sordidus costalis (Scud.)

1, 3 to 10, 15 and 16. Previous records are Edmonton, Steveville, Orkney, Lethbridge, Welling, New Dayton, Comrey and Walsh.

Northern records are Morinville and Heinsburg.

This widely distributed species occurs in about the same numbers as *Amphitornus coloradus* (Thos.)

Camnula pellucida (Scud.)

1 to 19. Previously recorded from a number of localities of which the most northerly are Edmonton and Cold Lake.

This is the most widely distributed and the second most abundant of the destructive species of grasshoppers in the province.

Pardalophora apiculata (Harris)

4, 7, 8, 9, 13, 14, 15. Previous records are Grande Prairie, Edmonton, Wabamun, Red Deer and Calgary.

Southern records are Millarville, Red Deer and Hughendon.

This insect, which is found in small colonies, matures in May and June. It frequently occurs in sandy areas in the park belt, particularly where *Eleagnus* is present.

Xanthippus corallipes latefasciatus (Scud.)

1, 3 to 6, 16. Previous records are Calgary, Pincher, Lethbridge and Medicine Hat.

Northwestern limits are Calgary and Halkirk.

This relatively scarce spring form is usually found in blow-out areas where there is considerable grama grass.

Cratypedes neglectus (Thos.)

1, 3, 4, 6, and 16. Previous records are Steveville, Fort Macleod, Macleod and Minda. Northern record is Hanna.

This is one of the rarer species in Alberta. It is found in much the same type of habitat as the previous species.

Dissosteira carolina (L.)

1, 3 to 6, 8, 15 and 16. Previous records are Lethbridge, Burdett, Medicine Hat, Walsh and Comrey.

This road-loving species is quite common in the southern part of the province. Its continuous distribution runs as far north as Rumsey and Youngstown. A single colony was found around a strip coal mine at Tofield in area 8. This record is 100 miles north of the previously known distribution.

Spharagemon equale (Say)

1, 3 to 7, 15. Previous records are Calgary, Brooks, Medicine Hat, Walsh, Minda, Manyberries, Orion, Bow Island, Whitla, Taber, Chin, Coaldale and Lethbridge.

The limits of northwestern distribution are Calgary and Wainwright.

Spharagemon collare (Scud.)

1, 3 to 8, 10, 15, 16. Previous records are Morrin, Calgary, Lethbridge, Bow Island, Medicine Hat, Walsh and Minda. Tinkham reports that he has collected it at Cold Lake.

The northwestern limits of distribution are Sundre, Ponoka, Bonnyville and Cold Lake.

Derotmema haydenii haydenii (Thos.)

1. First collected by Tinkham in 1938 at the Higdon Ranch, Comrey. It was taken from the same locality in 1939 (White and Neilson) and in 1940 (White and Rock).

Trachyrhachis kiowa kiowa (Thos.)

1 to 8. Previous records are Calgary, Lethbridge, Medicine Hat, Walsh, Minda and Comrey.

Camrose and McLaughlin are northern records.

This species is quite abundant in the plains section of the province.

Metator pardalinus (Sauss.)

1 to 8, 15 and 16. Previous records are Lethbridge, Macleod, Chin, Bow Island, Medicine Hat, Walsh, Cypress, Minda and Comrey.

Northern records of this species, common to grasslands, are Ponoka and Mannville.

Trimerotropis sparsa (Thos.)

1, 3 to 6. This variable species was first reported from Lethbridge in 1924 as *T. azurescens*. Since then it has been reported from Morrin, Drumheller, Lethbridge and Comrey.

The species is confined to eroded areas along cut banks in river valleys.

Trimerotropis gracilis sordida E. M. Walker

1, 3, 4 and 6. Previously reported from Brooks, Purple Springs, Bow Island, Whitla, Medicine Hat, Walsh and Minda.

Northwestern records are Lethbridge and Scapa.

The adults of this species are usually found in thin stands of dry short grass, along the edges of grain fields and in blow-out areas.

Trimerotropis pallidipennis salina McNeill

1, 3 to 7, and 9. Previous records are Edmonton, Steeveville, Orion, Comrey, Bow Island, Lethbridge, Macleod and Waterton Lakes.

Edmonton is the northernmost record of occurrence.

This species has a somewhat discontinuous distribution due to the fact that it is largely confined to saline areas.

Trimerotropis campestris McNeill

1 to 7, and 16. Previous records are Gull Lake, Calgary, Morrin, Pincher, Macleod, Lethbridge, Chin, Medicine Hat, Cypress, Minda and Comrey.

Gull Lake and McLaughlin are northern records for this, the most common member of the genus, in Alberta.

Trimerotropis pistrinaria Sauss.

1, 3, 4, 5 and 6. Previously recorded from Lethbridge, Bow Island, Medicine Hat and Comrey.

Northwestern records are Gleichen and Scapa.

This handsome species is usually found along bare river banks and eroded and gravelly areas in bad lands.

Trimerotropis agrestis McNeill

3. Previous records are Orion, Minda and Calgary (Caudell).

This sand-loving species has only been taken by the authors at Orion. It is possible that the record of Caudell, from Calgary in 1908, of *citrina*, which has since been determined as *agrestis*, is due to mislabelling and that the specimen was caught at Medicine Hat.

Trimerotropis laticincta Sauss.

1 and 3. This species was first collected by Tinkham at the Higdon Ranch, Comrey, in 1938. Since then it has been collected from a number of locations in Area No. 1 and at Seven Persons in Area No. 3.

Trimerotropis suffusus Scud.

16. Previously recorded from Blairmore, Coleman, Frank and Waterton Lakes. It has not been collected by the authors from localities other than these.

Circotettix verruculatus Kirby

8, 9, 10, 12, 13, 14, 17, 18 and 19. Previous records are Cold Lake, Athabasca, Edmonton, Primrose Lake, Lacombe, Nordegg and Banff.

Banff, Lacombe, Edmonton and Cold Lake are southeastern records.

Circotettix rabula rabula R. and H.

1, 3 to 8, 15 and 16. Previous records are Morrin, Steeveville, Coleman, Frank, Cowley, Fort Macleod, Macleod, Lethbridge, Medicine Hat and Comrey.

Cochrane, Delbourne and Meeting Creek are northwestern records. This species, which is largely confined to steep bare slopes, has a rather discontinuous distribution.

Aerochoreutes carlinianus carlinianus (Thos.)

1 to 8, 15 and 16. Previous records are Steeveville, Macleod, Lethbridge, Welling, Bow Island and Comrey.

Cochrane and Meeting Creek are northwestern records in Alberta. It has, however, been reported by Buckell and collected by the authors in bare slopes of the Peace River at Rolla and Fort St. John, in the Peace River Block.

Hadrotettix trifasciatus (Say)

1 and 3. Previous records are Medicine Hat, Comrey and Calgary (Caudell).

This species has been collected by the authors only from the vicinity of Medicine Hat, Manyberries and Comrey. Caudell's record, from Calgary, is possibly due to the interchanging Calgary and Medicine Hat labels as probably occurred with his record of *T. vinculata similis* Scud.

(*T. agrestis*.) *Schistocerca lineata* Scud.

1 and 3. Previously recorded from Medicine Hat and Comrey. This species has been collected by the authors only from the vicinity of Medicine Hat, Manyberries and Comrey.

Hypochlora alba (Dodge)

1. New record for the province.

Reared from nymphs collected seven miles S.E. of Comrey, July 13, 1939 (White). Hebard (4) gave the northern limits of this species as Brockton, Nashua, Glasgow and Havre, Montana.

The food plant of this species, *Artemisia ludoviciana* Nutt., is fairly local in distribution over southeastern Alberta. *H. alba* appears to be even more localized and is confined largely to gullies in the area from which it was collected.

Aeoloplus turnbulli turnbulli (Thos.)

1 to 6. Previously recorded from Drumheller, Minda, Cypress and Comrey.

Morrin and Hanna are northern records of distribution.

This handsome little grasshopper, which feeds largely in *Atroplex* and its allies, has rather a discontinuous distribution.

Hesperotettix viridis pratensis Scud.

1, 3, 4, 5. Previously recorded from Lethbridge, Fort Macleod and Comrey.

The northwestern records of this handsome species are Brocket, Dorothy and Buffalo.

In Alberta this insect is usually found on or near, *Gutierrezia sarothrae* (Pursh.) which is one of its host plants.

Melanoplus oregonensis oregonensis (Thos.)

16. New record for the province.

Carway 8♂♂, 6♀♀, June 30, 1939 (R. M. White). Collected on the north slope of the Milk River ridge in *Symphoricarpos* and tall grass, at 4500 ft. elevation.

Three males have the supra-anal plate slightly shorter than material of *M. oregonensis oregonensis* from Wyoming although, in other respects, it is quite typical of this material. The other five males have the supra-anal plate slightly wider and slightly shorter than is usual in this species. The furculae are also slightly divergent but longer than is typical in *M. oregonensis triangularis* from Waterton. These five specimens are best described

as atypical *M. oregonensis oregonensis* as they are closer to that sub-species than to *M. oregonensis triangularis*. This location is apparently an area of intergradation between the two races.

M. oregonensis oregonensis had previously been recorded from Logan Pass, Glacier Park, Montana, by Hebard in 1932. This location is at an elevation of 6650 ft. and is 20 miles S.W. of Carway.

Melanoplus oregonensis triangularis Hebard

16 and 17. Previous records are Middle Fork of Old Man River, Coleman, Blairmore, Waterton and Lake Bertha in Waterton Lakes Park.

Of 58♂♂ and 16♀ none show any tendency toward *M. oregonensis oregonensis*. Three males of the series have the lateral margins of the supra-anal plate much raised and thickened in the proximal half.

Melanoplus montanus (Thos.)

10, 13, 16, 17, and 18. Previously recorded from Moraine Lake, Lake Agnes, Mount Fairview, Laggan, Banff, Crow's Nest Pass, Blairmore, Lake Bertha, Waterton Lakes Park, Cold Lake, Shaftesbury and Fairview.

The species has been collected by the authors only from Waterton, Bellevue, Coleman and Exshaw.

Melanoplus huroni Blatch.

10, 13, 19. Previously recorded from Shaftesbury.

This species, which is one of the rarer *Melanopli* of Alberta, has been collected by the authors from Cold Lake, and Bonnyville in Area 10, Jasper in Area 19 and in a number of localities in the Peace River district.

Melanoplus bivittatus (Say)

1 to 17 and 19.

This species, which had previously been reported from a number of localities in the province, has been the third most injurious of the economic species. Only individuals with bluish-yellow, greenish-yellow or straw-coloured tibiae have been taken.

Melanoplus dawsoni (Scud.)

2 to 10, 13, 15, 16, 17. This widely distributed species has been recorded from a number of localities in the province.

It is quite abundant in the more humid plains section and in the black soil of the park belt adjoining those areas. In the Peace River district, Area 13, the species is largely confined to the more open places along the river valleys.

A macropterous specimen was taken at Onefour in 1940 (Rock).

Melanoplus gladstoni (Scud.)

1 to 7 and 17. Previous records are Banff, Calgary, Fort Macleod, Macleod, Granum, Lethbridge, Bow Island, Cypress and Comrey.

Northwestern records of this insect, which is usually found in dry uplands, are Banff, Wimbourne and Wainwright.

Melanoplus confusus Scud.

1, 3, 5, 7 and 8. The first published record was of a single female from the Higdon Ranch, Comrey, taken by Tinkham on July 17, 1938 and reported in 1939.

The following additional records are available:

Ribstone, Aug. 12, 1937; Heath, July 7, 1938; Morningside, July 11, 1938; Edgerton, Dunn, Aug. 23, 1938; Elnora, Lousana, July 23, 1939 (Rock).

Delbourne, July 10, 1938 (White and Rock).

Redcliff, June 7, 1938; Burdett, June 10, 1939 (White).

A single male is present from Estevan, Sask. collected, June 19, 1915 (N. Criddle).

These 27 ♂♂ and 15 ♀♀ all have glaucous tibiae ranging from quite deep to fairly weak. This is the earliest maturing species of the *Melanopli*, adults generally appearing about June 1. It is usually found in semi-upland locations or sand areas in close proximity to clumps of aspen poplars in Areas 5, 7 and 8. In the southern portion of the short grass prairies it is usually found close to trees along the river bottoms.

Melanoplus femur-rubrum femur-rubrum DeGeer

1 to 10 and 16. Previous records are Ponoka, Lethbridge, Medicine Hat and Walsh.

Northwestern records are Cowley, Calgary, Ponoka, Tofield and Myrnam.

This insect rarely reaches outbreak proportion in Alberta and then only in isolated, moist areas, particularly irrigated districts.

Melanoplus borealis borealis (Fieber)

18 and 19. New record.

This species was previously recorded from Banff and Beaverhill Lake as *extremus*, a synonym of *borealis borealis*, but this material was referred to *borealis monticola* by Hebard in 1930.

6 ♂♂ and 5 ♀♀ Athabasca Glacier, 6800 ft.: 4 ♂♂ and 4 ♀♀ Junction Athabasca and Whirlpool rivers, 5000 ft.: 1 ♀ Sunwapta Falls, 5000 ft.: 2 ♂♂ and 2 ♀♀ Mount Coleman, 6100 ft.: 8 ♂♂ and 9 ♀♀ Bow Summit, 6800 ft., July, 1939 and August, 1940 (Rock).

The material from Athabasca Glacier was collected within 50 to 200 yards of the glacier on springy soil covered by short, woolly grass, a species of low-growing birch and some mossy vegetation. There were numerous bare places with cherty exposures.

The specimens from Sunwapta Falls and the junction of the Athabasca and Whirlpool rivers and from Mount Coleman were collected in muskeg with a few dwarf birches and some short woolly grass. The specimens from Bow Summit were taken in a wide valley with a similar habitat to those from Athabasca Glacier.

These specimens were compared with, and found to be quite similar to, 2 ♂♂ of *borealis borealis* collected at Churchill, Manitoba, by D. C. Dunning, Aug. 9, 1937, and determined by A. B. Gurney. (Courtesy R. D. Bird). The specimens from the junction of the Athabasca and

Whirlpool rivers and from Sunwapta Falls are slightly larger than the Athabasca Glacier and Churchill material but still referable to *borealis borealis*.

Specimens, determined by Hebard, have been collected at Cold Lake, Aug. 1937 (White and Rock) and at Cypress Hills (White).

Melanoplus borealis monticola Scud.

2, 4, 13, 14, 15, 17 and 19. Previous records are Cold Lake, Beaverhill Lake, Jasper, Mount Fairview, Lake Agnes, Laggan, Banff, Macleod and Cypress.

The authors are separating the *monticola* material into three groups based on wing lengths as this race is supposed to be separated from *borealis* largely on "the reduction in the organs of flight" (Hebard (3) P. 397).

(a) Tegmina not extending beyond the basis of the genicular lobes of the caudal femora, 3 ♂♂ and 23 ♀♀. Henry House, Leech Lake Jasper National Park, Marlboro, Goodwin, Valleyview, Debolt, Hines Creek, Dixonville, Deadwood, Nesta and Ryley.

(b) Tegmina extending to a point between the basis of the genicular lobes and just beyond the apices of the caudal femora, 36 ♂♂ and 11 ♀♀. Henry House, Obed, Marlboro, Goodwin, Beaverlodge, Hines Creek, Grimshaw, North Star, Nesta, Donnelly, McLennan, Jousard, Wagner, and Nestow in Alberta: Pouce Coupe and Baldonnell, B.C. in the Peace River Block.

(c) Tegmina extending well beyond the apices of the femora, 12 ♂♂ and 8 ♀♀. Valleyview, Goodwin, Grosmont, Beaverlodge, Hines Creek, Bluesky, Whitelaw, Grimshaw, Notikewin, Jousard, Smith, Athabasca, Nestow, Duffield and Seba Beach. Some of the specimens of this group, both males and females, have the tegmina extending as much as 7 mm. beyond the apices of the caudal femora.

Some *monticola* individuals, taken at altitudes of 1900 to 3800 feet, from various locations in Alberta, are larger and lighter in colour than *borealis*.

The penes were exposed in a number of specimens of different wing-length. Some variation in the penes was observed but this variation did not appear to be correlated with length of the tegmina.

In a number of publications Hebard has stated that "*monticola* is the least well defined of the races of *borealis*." With this the authors heartily agree. They are strongly of the opinion that *monticola* should be synonymized but hesitate to suggest it as they have only seen material of this race from Alberta, Wyoming, southern Utah and Manitoba.

They also wish to thank E. H. Strickland for the loan of his material of this race, determined by Hebard.

Melanoplus borealis junius Dodge.

13. New record.

One male, collected July 15, 1938, Valleyview, Peace River district (Rock). This male is, to all appearances, identical to two males from Senkiw and Aweme, Manitoba (R. D. Bird) which were determined by Hebard.

The authors are doubtful of the validity of this weakly defined race, although the only material of *junius* that they have seen is from Manitoba.

Melanoplus infantilis Scud.

1 to 11, 13, 16 and 17. This insect has been recorded from a number of localities, the northernmost being Leduc.

North of Edmonton it is confined largely to the dry hillsides along river valleys. It has been taken in such habitats as Beaverdam, Cold Lake, Peace River and Dunvegan. South of Edmonton it is found in large numbers in grasslands.

Melanoplus alpinus Scudder

2, 16, 17. Previous records are Crow's Nest Pass, Blairmore, Fort Macleod and Cypress.

The species has been collected from a number of locations in the Cypress Hills and in the foothills, the most northerly record being Canmore. Bruner's specimens from Fort Macleod were evidently taken in the foothills west of Macleod.

Melanoplus kennicotti kennicotti Scudder

4, 15, 16, 13, 16, 17. Previously recorded from Banff and the South Fork of the Old Man River near Fort Macleod.

The most northerly records are from Brownvale and Fairview, in the Peace River district. It is the most abundant grasshopper in Jasper Park. In the plains section of the province it is not common and adults are usually found in short dry grass. In the more moist areas it is found in dry grass along river banks.

Three males, which constituted the first record for British Columbia, were taken July 16, 1938 (White and Rock) on the north bank of the Peace River at Taylor.

Melanoplus occidentalis occidentalis (Thos.)

1, 3, 4, 5, 16. Previously recorded from Comrey and Lethbridge.

Northwestern limits of this uncommon grass species are Cowley and Drumheller.

Melanoplus fasciatus (F. Walker)

2, 8 to 17, 19. Previous records are Cold Lake, Athabasca, Edmonton, Lagan, several locations near Banff, Crow's Nest Pass, Blairmore and Cypress.

Apart from the Cypress Hills, southeastern records are Waterton Cowley, Exshaw, Alix and McLoughlin. This is a common species in mountainous and wooded areas. Macropterous specimens have been taken at Perryvale, Athabasca, Lesser Slave Lake, McLennan, Hines Creek and Valleyview. A previous Edmonton record is based on the macropterous form.

A gynandromorphic specimen is in the collection from Sturgeon Heights, Peace River district, July 17, 1938 (Rock.) Male characteristics are visible in the insect only in the genitalia, of which the right half is male and the left half female. In detail, the cerci are complete and normal on

each side—a male cercus on the right and a female cercus on the left. The supra-anal plate is a combination of male and female characters; the right half has male characters, including the ridge adjacent to the median sulcus, and a fercula but the left half is almost typically feminine, lacking ridge and fercula. The male sub-genital plate is almost complete on the right side of the median line but the left half has the appearance of having had the apical half cut out. One dorsal and one ventral ovipositor valve is present in the left side but both valves are displaced distad-laterad. Except for their displacement they appear to be quite normal.

Melanoplus mexicanus mexicanus (Sauss.)

This, the most destructive species of the orthoptera in Alberta, has been recorded in the literature from a number of localities southeast of Lake Louise and Wetaskiwin.

Typical material was collected in a large number of localities in Areas 1 to 8, 16, 17 and from Perryvale and Athabasca in Area 12, Beaverlodge and Debolt, Area 13, and Taylor in the Peace River Block.

There is a typical material, in which the subgenital plate is more produced and not conspicuously notched and the furculae are much longer and heavier than in typical *mexicanus*, from the following points: Waterton, Banff, Castor, Hughendon, Edson, Obed, Beaverlodge, Grimshaw and from Taylor, B.C.

Melanoplus bruneri Scudder

2, 7 to 19. Area 19 is the only new record of distribution.

A typical material, in which the ferculae are shortened and the sub-genital plate less produced than in typical *bruneri*, was collected from Mountain View, Banff, Morley, Jasper, Wabamun, Edmonton, Myrnam, Bonnyville, Nestow, Peace River, Debolt, Fairview and Taylor, B.C.

In the transitional area of this province, where the park belt approaches prairie conditions, specimens which apparently intergrade between *bruneri* and *mexicanus* can be found. It would appear to the authors that *M. bruneri* might well be relegated to racial status, under *M. mexicanus*, as it appears to be merely a boreal form of that species.

Melanoplus keeleri luridus (Dodge)

3. Previously recorded from Minda, in Area 3.

This species has not been collected by the authors.

Melanoplus packardi packardi Scudder

1 to 16, 19. Previously recorded from Calgary, Fort Macleod, Lethbridge, Chin, Whitla, Medicine Hat, Minda and Comrey.

Jasper, Peace River, Perryvale and Cold Lake are northern records. A number of specimens were taken in the Jasper district, near Peace River and at Perryvale in which the rear tibiae were lilac-coloured when collected but which turned deep red when dry. These were determined by Mr. A. B. Gurney.

This, the fourth most injurious grasshopper to crops in Alberta, is quite plentiful over a wide range of habitats in Areas 1 to 11. All of the specimens taken in these areas have glaucous tibiae.

Melanoplus foedus foedus Scudder

Orion, in Area 3. New record for the province. A single male was collected among sand dunes at Orion, July 14, 1939 (White). Without examination of the internal genitalia the specimen would have been identified as *packardi*. Caudal tibiae are glaucous.

The previous northwestern records for the species as given by Hebard in 1932 were Missoula, Cascade and Forsyth, Montana.

Melanoplus foedus fluviatilis Bruner

4. New record.

A single teneral male was collected at Lethbridge, Aug. 10, 1933 (White) and determined by A. B. Gurney.

Columbus, Pompey's Pillar and Terry, Montana, are previous northwestern records.

This record is approximately 325 miles northwest of any previous record of distribution.

Melanoplus angustipennis (Dodge)

3 and 7. New to the province.

Previous northwestern limits for this inhabitant of sandy areas were Tortman, Glasgow and Poplar, Montana and Aweme, Manitoba.

5♂♂, 6♀♀, July 13, 1933, July 14, 1939 (White); 1♂ Orion, July 14, 1939 (C. L. Neilson); 1♂, 1♀, Czar, Aug. 18, 1938, 2♂♂, 2♀♀, Hughendon, Aug. 23, 1939, 7♂♂, 6♀♀, Orion, July 16, 1940, 1♂, Comrey, July 14, 1940 (Rock).

Melanoplus flavidus flavidus Scudder

3, 4, 5 and 7. Previous records are Drumheller, Lethbridge and Medicine Hat.

The northern record of this grass-feeding inhabitant of sand areas is Heath.

There is a possibility that the previous records from Lethbridge, Medicine Hat and Drumheller refer to *M. bowditchi canus*. Although *flavidus* and *bowditchi canus* are easily distinguishable in the field, difficulty was experienced in separating dried material until the penes were compared.

The writers have taken authentic specimens of *flavidus* only from Metiskow, Hughendon, Amisk, Heath, Ribstone and Orion.

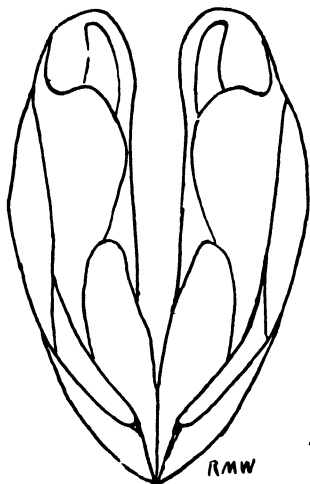
Melanoplus bowditchi canus Hebard.

1, 3, 4 and 5. Previous records are Morrin, Lethbridge, Medicine Hat and Comrey.

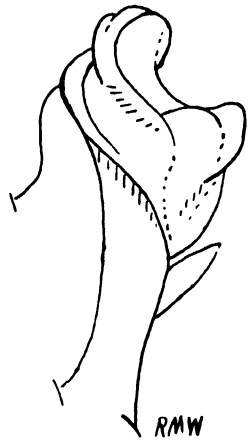
Morrin and Empress are northern records.

This inhabitant of sage brush areas has been taken only from around, or on, *Artemisia cana* Pursh. and is usually confined to eroded areas and river valleys. Dried specimens may easily be confused with *M. flavidus* but are readily distinguished by comparing the penes.

Drawings of this organ of *M. flavidus* and of *M. bowditchi canus* are shown in Figures 2 and 3, respectively.

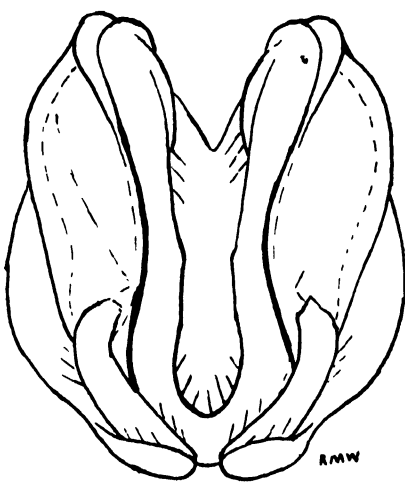


a. Caudal View



b. Lateral View

Fig. No. 2
Penis
M. flavidus



a. Caudal View



b. Lateral View

Fig. No. 3.
Penis
M. bowditchi canus

Asemoplus montanus (Bruner)

16. This previously incorrectly recorded species was first collected by E. R. Buckell at Bellevue. Material was collected at Waterton and Bellevue, Sept. 19 and 20, 1939 (White).

The species had been reported in error from Waterton by Hebard in 1928, but this was corrected by him in 1930, the material actually representing *A. somesi* Hebard.

Asemoplus somesi Hebard

16 and 17. Previous records are Banff, Lake Louise, Blairmore, Waterton and Lake Bertha, Waterton Lakes Park. This species has been collected by the authors only from the above localities.

Asemoplus hispidus (Bruner)

Hebard, in 1930, writes of this species, "The only record of this species, to which *somesi* is closely related, is that part of the original series of the synonym *Podisma nuda* Walker from Mount Piron near Laggan (Lake Louise)."

The authors have not collected it.

Phoetaliotes nebrascensis (Thos.)

1, 3, 4 and 5. Previous records are Fort Macleod, Macleod, Lethbridge, Medicine Hat. Walsh and Comrey.

Northern records of this rather uncommon species of the grasslands of southern Alberta are Gleichen and Hilda.

ACKNOWLEDGMENTS

The authors are greatly indebted to Prof. E. H. Strickland, University of Alberta, for permission to use his data in the Description of Ecological Areas. These descriptions were found to be remarkably complete, accurate and just the information required.

Gratitude is expressed also to Messrs. A. B. Gurney, M. Hebard, J. A. G. Rehn, H. C. Severin and E. R. Buckell for their determinations of material.

REFERENCES

1. CAUDELL, A. N. Notes in Some Western Orthoptera with the description of one new species. *Proc. N.S. Nat. Mus.* April 17, 1908.
2. HEBARD, MORGAN. The Orthoptera of Montana. *Proc. Acad. Nat. Sci. Phil.* 80 : 211 : 306. 1938.
3. HEBARD, MORGAN. The Orthoptera of Alberta. *Proc. Acad. Nat. Sci. Phil.* 72 : 377 : 403. 1930.
4. HEBARD, MORGAN. Notes on Montana Orthoptera. *Proc. Acad. Nat. Sci.* 74 : 251 : 257. 1932.
5. HEBARD, MORGAN. Orthoptera of Minnesota Tech. Bull. 85. Univ. of Minn. Agri. Exp. Sta. 1932.
6. HEBARD, MORGAN. Orthoptera of North Dakota. Bull. 284. Agri. Exp. Sta. North Dakota, Agr. Coll. Fargo. 1936.
7. STRICKLAND, E. H. An annotated list of the diptera (Flies) of Alberta. *Can. Jour. of Research, D*, 16 : 175-219. 1938.
8. TINKHAM, E. R. Five new records and notes on Canadian Acrididae from the Higdon Ranch, South Eastern Alberta. *Can. Ent.* LXXI : 121-126. 1939.
9. GURNEY, ASHLEY BUELL. A revision of the grasshoppers of the genus *orphulella* Giglio Tos from America North of Mexico (Orthoptera Acrididae) *Entomologica Americana* Vol. XX No. 3, pp. 85-157, Aug. 17. 1940.

PINK ROT DISEASE OF POTATOES IN BRITISH COLUMBIA¹

WALTER JONES²

Dominion Laboratory of Plant Pathology, Saanichton, B.C.

[Received for publication March 21, 1945]

In the autumn of 1943 a few diseased potato tubers that exhibited symptoms not previously seen by the author were obtained from the Okanagan district of British Columbia. These symptoms were somewhat similar to those associated with blackleg and *Pythium* soft rot. On microscopic examination, coenocytic mycelium was found within the diseased tissue, and when the fungus was isolated and cultured it was identified as *Phytophthora erythroseptica* Pethy. This was first described by Pethybridge (1) as the cause of the pink rot disease of potatoes in Ireland. According to McLarty (2), the disease was found in localized areas of one Okanagan field, and caused a crop loss of approximately 30% owing to wilt, stem decay, and the rotting of the tubers.

EXPERIMENTAL METHODS AND RESULTS

Symptoms of Diseased Tubers

In artificially inoculated tubers of different varieties, the most characteristic external symptom was a dark discoloration of the lenticels. This was quite pronounced in the young tubers and in the tubers of white skinned varieties (Plate 1). Where it was possible to skin the affected parts, the tissue adjacent to the lenticels appeared as distinct black spots on the surface of the dull white flesh. Other external symptoms were a dullness of the skin and a purplish discoloration of the eyes. The surface discoloration varied with the varieties. Thus, in the Netted Gem and the Columbia Russett varieties, the diseased tubers appeared almost normal, while in the Burbank and the White Rose varieties, the diseased areas were much darker than the healthy areas (Plate 1). The affected tubers were fairly firm but somewhat resilient, and when pressed, a brownish watery liquid oozed through the broken skin. These latter symptoms are somewhat similar to those associated with the tuber soft rot caused by *Pythium ultimum* Trow., as reported by Jones (3).

Immediately after cutting, the flesh of the diseased tubers appeared dirty white and moist, but after a few minutes exposure to the air, a faint pink colour developed. Within a half-hour period, the whole of the cut surface assumed a deep salmon pink colour which after a long exposure, changed to a purplish black. When the affected tubers were kept relatively dry, the texture of the diseased tissues remained fairly firm and somewhat leathery, but when kept in a moist chamber or in the soil, they rotted, and whitish mycelial tufts of secondary organisms developed on the lenticels. In general, the above symptoms agree with those described by Pethybridge (1).

¹ Contribution No. 814 from the Division of Botany and Plant Pathology, Science Service, Dominion Department of Agriculture, Ottawa, Canada.

² Assistant Plant Pathologist.

The Pathogen

The fungus grew readily in culture, and on malt and potato dextrose agar media produced numerous oospores. When pieces of mycelium were transferred to a solution of M/100 potassium nitrate, a few sporangia developed. These were usually single and terminal but on rare occasions the conidiophores were sympodially branched (Plate 2). The morphological characteristics of the oogonia, the antheridia, the oospores, the sporangia, and the mycelium agree with those described by Pethybridge (1).

Pathogenicity of the Fungus to Tubers of Different Varieties

Five potato tubers each of the varieties Warba, Epicure, Irish Cobbler, White Rose, Netted Gem, Burbank, Green Mountain, Columbia Russett, and Sequoia were used for this experiment. By means of a cork borer, tissue was taken out from the stem end of each tuber to a depth of a quarter of an inch. After uniform discs of an actively growing culture were placed inside the cavities, the plugs of the tuber tissue were re-inserted and sealed with paraffin wax. The tubers were then incubated at 24° C.

All the tubers developed symptoms of the pink rot disease, and after 6 days, no significant difference in varietal susceptibility was found.

Pathogenicity of the Fungus to Growing Plants and Tubers

This was determined in the greenhouse by planting potato tubers of the Warba variety in steam sterilized soil, and in steam sterilized soil inoculated with diseased potato tissue obtained from artificially inoculated tubers. Two test series were run, with 10 inoculated and 5 check pots in each series.

Inoculation of the soil was done by cutting diseased tubers into quarters and placing 8 of these quarters a few inches below soil level in each pot. Small whole tubers of the Warba variety, previously dipped in an organic mercury solution were then planted. In the first series, the potatoes were planted in February, and the plants dug up and examined 20 days later before any tubers had developed. In the other series, the potatoes were planted in March, and the plants were allowed to grow until good sized tubers had developed.

In the first series, all the check plants grew normally. In the inoculated pots, 4 of the mother tubers had rotted, and 6 were normal. The sprouts that grew from 5 of the tubers showed brown, necrotic lesions rather similar to those associated with *Rhizoctonia* infection (Plate 1). Within this necrotic tissue, oospores of the fungus were present.

In the second series, all the plants and tubers in the check pots were healthy. In the inoculated pots, all the plants grew normally throughout the early growth period, but a few leaves of some of the plants wilted during the later stages of growth. The harvested tubers of 2 plants were all healthy, while the tubers of 1 plant were all affected with the pink rot disease. Each of the other 7 pots contained some healthy tubers and some tubers affected with pink rot. On a few stems, the tissues of the basal parts were shrunken and necrotic, and aerial tubers were produced on the stems of 2 plants (Plate 1).

Growth Temperature of the Fungus

Inoculum from an actively growing culture was transferred to plates containing malt agar and incubated at the following temperatures: 4° C., 8° C., 20° C., 24° C., 28° C., and 34° C. Five plates were used for each series. After 6 days, the average growth was respectively 0, 2, 6, 7.5, 3.5 and 0 centimetres in diameter. The results indicate that the optimum temperature for growth of the fungus is approximately 24° C., the minimum between 4° C. and 8° C., and the maximum below 34° C.

Pathogenicity of the Fungus to Potato Tubers at Different Temperatures

Potato tubers of the Burbank variety were used in this experiment because the external symptoms of the disease are well defined in this variety. Thirty tubers were inoculated with a pure culture of the fungus and incubated at 4° C., 8° C., 20° C., 25° C., and 28° C., with 6 tubers at each temperature.

The rate of infection was determined by measuring the extent of the decay from the stem to the apical ends, with index "one" representing the maximum decay. Slight symptoms of the disease were observed on the second day in the series incubated at 20° C., 25° C. and 28° C. On the fifth day, the average indices of infection at these temperatures were .5, .8 and .6, and on the sixth day, .7, 1.0, and .8, respectively. At the end of the sixth day there were no symptoms of decay in the tubers incubated at 4° C. and 8° C.

These results indicate that the optimum temperature for the development of the pink rot disease in potato tubers is approximately 25° C.

DISCUSSION

Pethybridge (4) claimed that the parasite was found in all the underground parts of the plant, and that oospores were present in the diseased tissue. He also stated that the parasite can cause a wilt disease which usually appears late in the season, and that frequently a crop of small aerial tubers may be produced. These observations agree with the results obtained in the above pathogenicity experiment with growing plants. It is interesting to note that cortical necrosis of the sprouts as well as the formation of aerial tubers are field symptoms usually attributed to *Rhizoctonia* infection. In this experiment, there was a slight wilting of some of the leaves of the plants which were grown in the inoculated pots, but otherwise there was no significant difference between them and those grown in the check pots. Numerous tubers, however, of the plants grown in the inoculated soil were affected with the pink rot disease. This indicates that the disease is essentially a tuber disease, and that infection of tubers may occur in the soil during growth where the pathogen is present.

Control Measures

To control the disease, Pethybridge (4) recommends growing potatoes only on land in proper rotation, and the removal and destruction of all affected parts, including the diseased tubers.

Since the optimum temperature for the growth of the fungus is approximately 24° C., and that for the development of the disease in tubers is

approximately 25° C., it is obvious that care should be taken to remove all diseased tubers at harvesting time. This is particularly important in the case of tubers harvested during warm weather, and in those stored or shipped at relatively high temperatures.

SUMMARY

1. The fungus *Phytophthora erythroseptica* Pethy., the causal organism of the pink rot disease, was isolated from diseased potato tubers obtained from the Okanagan district of British Columbia.

2. The symptoms of the disease in inoculated tubers are a dark discoloration of the lenticels, a dullness of the skin, and purplish discoloration of the eyes; the flesh on cutting is dirty white, turning to faint pink, then to deep salmon pink within one-half hour.

3. The fungus proved pathogenic to potato tubers of the varieties Warba, Epicure, Irish Cobbler, White Rose, Netted Gem, Burbank, Green Mountain, Columbia Russett and Sequoia. All appeared to be equally susceptible.

4. Plants grown in soil inoculated with the fungus developed symptoms of pink rot in the mother tubers and in young tubers, as well as necrosis of stolons, sprouts, and basal parts of the stems, and wilt of some of the leaves towards the end of the growing period.

5. The optimum temperature for the growth of the fungus is approximately 24° C., the minimum between 4° C. and 8° C., and the maximum below 34° C.

6. The optimum temperature for the development of the disease in potato tubers of the Burbank variety is approximately 25° C.

7. Control measures consist in crop rotation, destruction of diseased refuse, and careful grading of the crop before putting in storage or before marketing.

REFERENCES

1. PETHYBRIDGE, G. H. On the rotting of potato tubers by a new species of *Phytophthora* having a method of sexual reproduction hitherto undescribed. *Sci. Proc. R. D. S.* XIII : 35; 529-565. 1913.
2. McLARTY, H. R. Private communication, October, 1943.
3. JONES, W. Soft rot of potatoes caused by *Pythium ultimum* Trow. *Sci. Agric.* 15 : 6; 402-410. 1935.
4. PETHYBRIDGE, G. H. Further observations on *Phytophthora erythroseptica* Pethyb. and in the disease produced by it in the potato plant. *Sci. Proc. R.D.S.* XIV : 10; 179-198. 1914.

THRESHING-INJURY TO FLAX SEED IN CANADA¹

J. E. MACHACEK AND A. M. BROWN²

Dominion Laboratory of Plant Pathology, Winnipeg, Manitoba

[Received for publication April 18, 1945]

In 1940, when 62 different lots of No. 1 C.W. commercial flaxseed, treated and untreated, were sown in non-sterile soil in a greenhouse, it was found that in some lots the treated seed showed a marked improvement in germination, while in other lots the treated and the untreated seed germinated equally well. At first it appeared that this difference was due to some varietal influence, or to a variation from lot to lot in the percentage of seeds infected with pathogenic micro-organisms. Subsequent tests revealed that neither of these factors was apparently involved. There was frequently a greater difference, in their response to seed treatment, between two seed lots of any given variety than there was between two seed lots of different varieties. A plating-out test of non-sterilized seed showed that the seed responding most markedly to seed treatment was often relatively free from micro-organisms. Furthermore, when the 62 lots of commercial seed were planted in autoclaved soil, in almost every case the untreated seed germinated as well as did the treated seed. These findings indicated that soil-borne, instead of seed-borne, micro-organisms were responsible for the differences in seed germination observed when treated and untreated flax seed was planted in non-sterile soil.

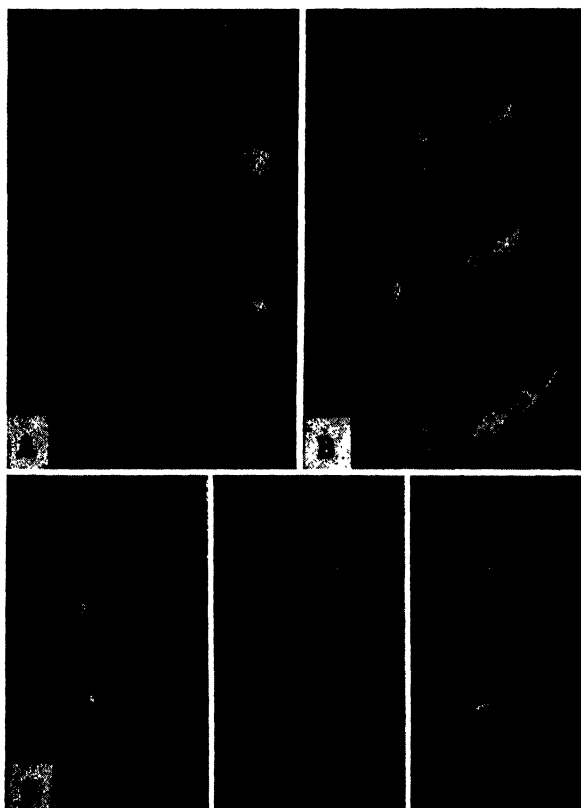
It was not until seed from different lots of flax was scrutinized through a low-power binocular microscope that the cause of the differences in seed germination became apparent. The seed lots responding to seed treatment contained fractured kernels (Figure 1B) in percentages proportional to the degree of response to seed treatment. These fractures were usually minute and escaped observation by the unaided eye, but they were deep, and in most kernels extended into the cotyledons. It appeared, therefore, that, when fractured kernels were planted in non-sterile soil, soil-borne micro-organisms invaded the kernels through the fractures and prevented them from germinating. On the other hand, when the seed was treated, the kernels were protected from such invasion and, on germination, produced seedlings with cotyledonary leaves bearing scars where the fractures had occurred (Figure 1C).

An investigation showed that fracturing of flax kernels occurred when the seed was threshed by machines equipped with a steel threshing cylinder. There was no fracturing when flax was threshed by hand or when the plants were passed between two rubber rollers.

In view of the increased importance of the flax crop during the present wartime emergency, it was thought desirable to investigate the prevalence and the economic significance of threshing-injury to flax in Canada, and to study ways of preventing losses from this injury. A preliminary report regarding this investigation has already been published (3). The results of more detailed experiments, carried on from 1940 to 1943, inclusive, are summarized and discussed in this paper.

¹ Contribution No. 828 from the Division of Botany and Plant Pathology, Science Service, Dominion Department of Agriculture, Ottawa, Canada.

² Assistant Plant Pathologists.



■ FIGURE 1. Threshing-injury to flax seed. A. Uninjured kernels. B. Fractured kernels. C. Seedlings from treated, fractured seed showing scars on cotyledonary leaves.

REVIEW OF LITERATURE

It appears that Stevens (7) was the first to draw attention to threshing-injury in flax. He reported that fractured kernels germinated poorly in the germination chamber and in the field. Härtel (2) also found that fractured flax kernels germinated poorly in the laboratory, and suggested that the seed became fractured when the crop was threshed during excessively dry weather. Schuster and his co-workers (6) reported that threshing-injury to flax occurred in the State of Washington. Their findings, in general, were similar to those obtained earlier (3) by the present writers. Moore and Christensen (5) found that mechanical fracturing of the seed coat was prevalent in flax seed from the United States and from Canada, and that injured seed, particularly that of golden-seed varieties, responded more to seed treatment than did uninjured seed.

MATERIALS AND METHODS

The flax seed used in the present investigation was obtained from a number of different sources. Thus, for a survey of the prevalence of threshing-injury in Canada, a large number of seed samples were obtained from farms, either directly or through the agency of various elevator com-

panies (North-west Line Elevators Association, Manitoba Pool Elevators Ltd., and United Grain Growers Ltd.) and the Manitoba Department of Agriculture. For a study of the relation of threshing-injury to market grade, samples from carload lots of flax seed were obtained through the courtesy of the Grain Inspection Division, Department of Trade and Commerce, Dominion of Canada. Additional seed lots, drawn from various experimental farms and stations across Canada, were used to determine the amount of threshing-injury in different varieties of flax. Finally, uninjured lots of seed were obtained by threshing flax plants by means of an ordinary clothes wringer.

The percentage of fractured kernels in a sample of flax seed was determined by one or more of the three following methods:

Method 1. A 100-kernel lot was spread in a one-layered narrow band on the adhesive side of a cellulose tape (Durex). The tape, with the attached seeds, was then drawn slowly across the field of a low-power binocular microscope and a count was made of the fractured kernels.

Method 2. A 100-kernel lot was taken from a seed sample, treated with diluted New Improved Ceresan, and then planted in non-sterile soil in the greenhouse. When the seedlings had emerged they were counted, and then a second count was made of the seedlings with scarred cotyledonary leaves (Figure 1C). The ratio of the second total to the first total was used to obtain the percentage of deeply-fractured kernels.

Method 3. Two 100-kernel lots were taken from each seed sample and, after one of these lots had been treated with diluted New

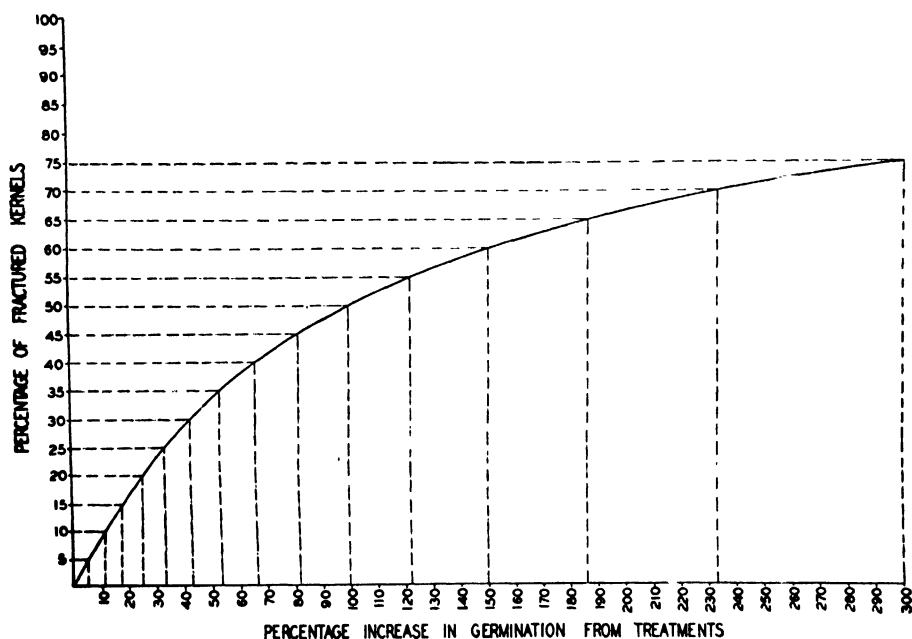


FIGURE 2. Relation of the percentage of fractured kernels in flax to the percentage increase in germination resulting from seed treatment.

Improved Ceresan, both lots were planted in adjacent rows in a bed of non-sterile soil. The percentage increase in germination resulting from seed treatment was determined and this value was interpolated on the graph shown in Figure 2. This interpolation showed, on the ordinate axis, the percentage of fractured kernels in the seed. The method was found to be inaccurate for seed containing many kernels infected by pathogenic micro-organisms, for the readings from the graphs were too high in comparison with the values obtained by Methods 1 and 2. As the majority of the flax seed samples tested were relatively free from infection and considerable information regarding the seed could be obtained through this method, it was the one generally followed.

In experiments to compare the protective value of different seed disinfectants, the disinfectants were usually applied as prescribed by their manufacturers. In routine tests, however, diluted New Improved Ceresan was regularly used to treat the seed. This disinfectant was chosen primarily because it was the one most readily available during the period of this study. When it was used diluted, one volume of it was mixed with two volumes of talc. In treating seed, a small quantity of the dilute disinfectant was poured into a glass beaker, the seed was then added, and, after thorough mixing, the excess dust was screened off into a second beaker. By a series of determinations with mixed lots of flax seed, it was found that the maximum amount of dust retained on the seed was 13.79 ounces to the bushel. This quantity of dust did not seem to harm the seed at all and its use prevented the loss of time required for the weighing out of minute quantities of undiluted dust. The protection afforded by this load of dilute dust was found to be about equal to that given by 1.5 ounces of undiluted New Improved Ceresan added to a bushel of seed.

The soil used for the tests was previously adjusted to a suitable degree of friability by a method described elsewhere (4). In all experiments, except those in which soil temperatures were involved, the soil was placed in frames on greenhouse benches. In experiments involving soil temperatures, the soil was put in 1-gallon earthenware jars held in Wisconsin-type temperature tanks. When sterile soil was required, the adjusted soil was put in 1-gallon containers and steamed for 3 hours at 15 pounds pressure.

The majority of the field experiments discussed in this paper consisted of 3-row plots (rows 10 feet long and 1 foot apart) arranged in randomized blocks, with at least 6 replicates of each treatment, and sown by hand. The middle row in each plot was used to obtain information regarding seed germination and yield, while the 2 lateral rows were used as buffers. In other field experiments, the plots were 1/100 acre in size and were arranged either in randomized blocks or in Latin squares. These larger plots were sown with a horse-drawn drill which spaced the rows 6 inches apart.

In the greenhouse, where the temperature was held at approximately 70° F., counts of plants were made 10 days after the seed was sown. In the field, however, the plants were not counted until they were mature.

When the plants in the field were ripe, those in the 10-foot row experiments were pulled, and then threshed by passing them between the rollers

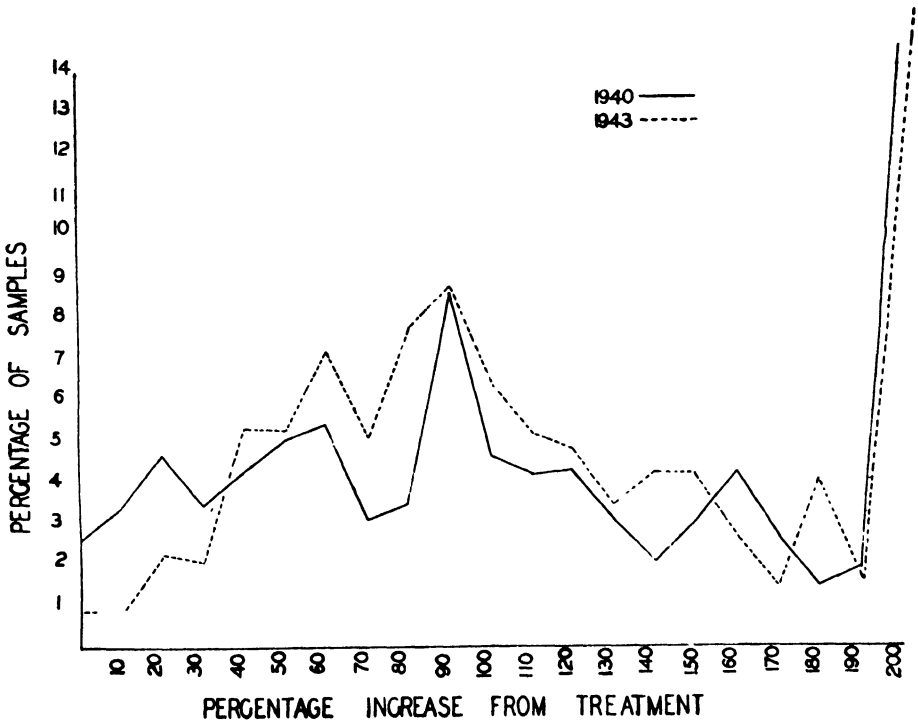
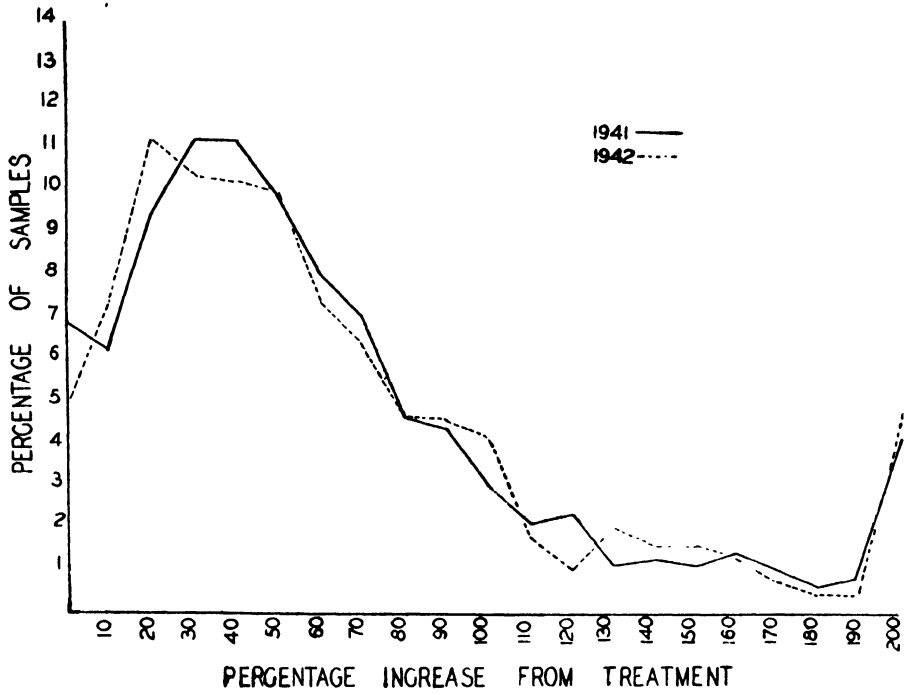


FIGURE 3. Percentages of seed samples with different degrees of threshing-injury. Above: crops of 1941 and 1942. Below: crops of 1940 and 1943.

of an ordinary hand-operated clothes wringer. The plants in the 1/100 acre plots were usually cut, after the border rows had been discarded, with a binder, and then threshed with a power-driven, stationary thresher.

Germination and yield data of most of the greenhouse and field experiments reported in this paper were analyzed statistically by the analysis of variance method.

PREVALENCE OF THRESHING-INJURY IN CANADA

General Distribution

In all, 2,630 samples of flax seed from different parts of Canada, and produced during the years 1940 to 1943, inclusive, were tested for threshing-injury. These tests showed that, in the 253 samples of the 1940 crop that were tested, on the average 52% of the kernels were fractured, while in 1,161 samples from the 1941 crop, in 608 samples from the 1942 crop, and in 608 samples from the 1943 crop, the average percentage of fractured kernels was 35%, 35%, and 52%, respectively.

The striking similarity in the percentage of fractured kernels between the crops of 1940 and 1943, and between those of 1941 and 1942, was emphasized by a further comparison of seed samples. When these samples were grouped in classes according to the percentage increase in seed germination resulting from seed treatment, it was found (Table 1) that the percentage of samples falling into corresponding classes was similar for the years 1940 and 1943, and also for the years 1941 and 1942. These similarities are shown graphically in Figure 3.

TABLE 1.—EXTENT OF THRESHING-INJURY IN THE FLAX CROPS OF 1940, 1941, 1942, AND 1943. THE PERCENTAGE OF SEED SAMPLES AT DIFFERENT LEVELS OF SEED INJURY

Level of threshing-injury (Increase in seed germination from treatment)	Percentage of seed samples							
	Actual percentage at level of injury indicated				Total percentage with injury at level indicated or higher injury			
	1940	1941	1942	1943	1940	1941	1942	1943
0 - 10	2.7	6.9	5.0	0.9	100.0	100.0	100.0	100.0
11 - 20	3.5	6.2	7.4	0.9	97.1	92.9	93.5	98.9
21 - 30	4.7	9.5	11.3	2.3	93.5	86.6	86.1	97.9
31 - 40	3.5	11.3	10.5	2.1	88.8	77.0	74.8	95.6
41 - 50	4.3	11.3	10.3	5.2	85.2	65.7	64.2	93.4
51 - 60	5.1	9.9	10.0	5.2	80.9	54.3	53.9	88.1
61 - 70	5.5	8.0	7.5	7.2	75.8	44.4	43.8	82.8
71 - 80	3.1	7.0	6.4	5.0	70.2	36.4	36.3	75.6
81 - 90	3.5	4.6	4.7	7.8	67.1	29.3	29.9	70.5
91 - 100	8.6	4.4	4.6	8.8	63.5	24.7	25.1	62.7
101 - 110	4.7	3.1	4.2	6.4	58.8	20.2	20.5	53.9
111 - 120	4.7	2.2	1.9	5.2	50.1	17.0	16.2	47.5
121 - 130	4.3	2.4	1.1	4.8	45.4	14.8	14.2	42.2
131 - 140	3.1	1.2	2.1	3.5	41.0	12.4	13.1	37.3
141 - 150	2.7	1.3	1.6	4.3	37.9	11.1	11.0	33.8
151 - 160	3.1	1.2	1.6	4.3	35.1	9.7	9.3	29.5
161 - 170	4.3	1.4	1.4	2.7	31.9	8.5	7.7	25.2
171 - 180	2.7	1.1	0.8	1.5	27.6	7.0	6.2	22.4
181 - 190	1.5	0.6	0.4	4.1	24.8	5.9	5.4	20.9
191 - 200	1.9	0.8	0.4	1.7	23.3	5.2	4.9	16.8
201 +	21.3	4.3	4.4	15.0	21.3	4.3	4.4	15.0

It was most difficult to account for the similarities within the pairs of years and for the differences between the pairs. After an examination of several possibilities, it was concluded that coincidental similarities in weather conditions prevailing during threshing were responsible. The weather was relatively dry at threshing time in 1940 and 1943 (threshing-injury severe), while, in 1941 and 1942 (threshing-injury moderate), it was moist. This conclusion was supported by the observations of Härtel (2), and also by the results obtained from a study of the market grades of flax seed from the crops of these four years. The flax from the crops of 1940 and 1943 graded well, most of it falling into grade No. 1 C.W. or No. 2 C.W. Some of the seed of the 1941 and 1942 crops fell into these high grades, but the bulk of it, chiefly on account of weathering and moulding resulting from prolonged moist weather, fell into lower grades. It appeared, therefore, that dry flax seed was very brittle and easily fractured during threshing, while flax seed of relatively high water content, being less brittle and also buffered to some extent by the spongy material from moist bolls, was not so subject to injury. A few seed lots from the 1941 and 1942 crops were weathered as well as fractured, and many of the kernels were actually fragmented. This condition of the seed indicated that an attempt had been made to thresh the flax when it was damp; and, to overcome the difficulty involved, the teeth of the concaves and cylinder of the thresher had been set too close, with the result that the seed received considerable injury even though it was damp.

Occurrence of Threshing-Injury in Different Areas

Most of the samples of flax seed studied originated in Western Canada (Manitoba, Saskatchewan, and Alberta), and only relatively few in Eastern Canada. This unequal distribution in respect to the source of seed did not permit a fair comparison of the two areas in respect to the prevalence of threshing-injury in them; but the results of the tests suggested that the seed from Eastern Canada, probably on account of moister weather at threshing time, was much less injured than that from Western Canada.

The distribution of threshing-injury in Western Canada is shown in Table 2. In each year of the four years during which seed samples were tested, flax seed originating in Manitoba was slightly less injured than that from Saskatchewan and Alberta. This difference, again, could be attributed only to a difference in weather conditions during threshing.

Occurrence of Threshing-Injury in Different Commercial Grades of Flax

Tests with 565 officially-graded samples of flax seed showed (Table 3) that there was apparently no relation between the commercial grade of flax seed and the percentage of fractured kernels in it. This result might be expected, because flax seed is graded largely on the basis of its appearance; that is, high grades are given to seed that is bright and glossy, while low grades are given to seed that is dull and off-colour. The appearance of the seed depends, however, on the kind of weather *before* it is threshed, while the percentage of fractured kernels in the seed seems to depend on the kind of weather *during* which it is threshed. Thus, bright seed, as well as weathered seed, will contain many fractured kernels when threshed during dry weather and relatively few when threshed during moist weather. On

this account, lightly-fractured and severely-fractured lots of seed may fall into the same grade, and, as the present observations indicate, the average injury to seed may be no greater in one grade than in another.

TABLE 2.—AVERAGE PERCENTAGE OF FRACTURED KERNELS IN FLAX SEED PRODUCED IN MANITOBA, SASKATCHEWAN, AND ALBERTA DURING 1940, 1941, 1942, AND 1943

Crop year	Province			Mean
	Manitoba	Saskatchewan	Alberta	
1940	49	63	51	51.0
1941	33	37	36	35.3
1942	32	35	34	33.6
1943	47	51	54	50.6
Mean	40.2	46.5	43.7	

TABLE 3.—AVERAGE PERCENTAGE OF FRACTURED KERNELS IN DIFFERENT COMMERCIAL GRADES OF FLAX IN 1940, 1941, 1942, AND 1943

Grade	Crop year			1943
	1940	1941	1942	
No. 1 C.W.	52	36	27	52
No. 2 C.W.	—*	33	30	47
No. 3 C.W.	—	35	27	43
No. 4 C.W.	—	34	—	—

* No samples available.

Occurrence of Threshing-Injury in Different Varieties of Flax

It was suggested earlier (3), and this view received support by Schuster *et al.* (6), that threshing-injury was more severe in large-seeded varieties of flax than in small-seeded ones. A recent study of 15 varieties of flax grown at each of nine experimental stations in different parts of Canada, and in two different years, indicated that there was a relatively close relation between the size of flax kernels and the percentage of them that were fractured. Data relating to 4 of these varieties are given in Table 4. Two of these varieties (Royal and Bison) are large-seeded and were, for the 15 varieties studied, on one end of the kernel-size scale, while the other 2 varieties (Redwing and Gossamer) are small-seeded and were at the other end of the kernel-size scale. The weights, per 1000 kernels obtained from composites made up of 16 samples of each variety, were as follows: Royal, 5.90 gm., Bison, 5.60 gm., Redwing, 4.77 gm., and Gossamer, 4.35 gm.

TABLE 4.—RELATION OF KERNEL SIZE IN FLAX TO THE PERCENTAGE OF FRACTURED KERNELS IN THE SEED

Source of seed	Percentage of fractured kernels							
	1940 seed				1941 seed			
	Large kernels		Small kernels		Large kernels		Small kernels	
	Royal	Bison	Red-wing	Goss-amer	Royal	Bison	Red-wing	Goss-amer
Nappan, N.S.	32	20	25	—	0	0	0	—
Morden, Man.	83	62	45	60	36	41	12	28
Brandon, Man.	49	35	41	15	5	25	12	3
Melfort, Sask.	57	68	52	48	10	15	0	4
Swift Current, Sask.	65	78	70	90	28	28	15	34
Scott, Sask.	59	56	54	62	56	58	62	—
Lethbridge, Alta.	79	39	56	53	50	48	47	34
Lacombe, Alta.	24	27	21	14	22	23	19	29
Beaverlodge, Alta.	81	92	66	70	28	28	23	0
Mean*	58.7	53.0	47.7	47.7	26.1	29.5	21.1	18.8
Mean†	55.8		47.7		27.8		19.9	

* Mean of stations.

† Mean of large-seeded and small seeded varieties.

Effect of Soil Type and Soil Temperature on Germination of Fractured Flax Seed under Greenhouse Conditions

Flax has been grown in Western Canada reasonably successfully on a wide variety of soils. Ordinarily, however, farmers have found it advantageous to plant less seed per acre on light soils than on heavy soils. This, in part, was due to the fact that flax seed seemed to germinate better in light than in heavy soils.

One of the reasons for the better germination in light soils seems to be that fractured flax seed is less likely to decay in light soil than in heavy soil. When, during this investigation, 30 different lots of flax seed were planted in each of four different soils, it was found (Table 5) that fractured seed, when treated, germinated equally well in all four soils; but, with untreated seed, the percentage germination decreased with each increase in soil density.

Treated, fractured seed appeared to germinate equally well in a range of temperature from 10° C. to 30° C. (Table 6), but the rapidity of germination was highest at 30° C. In untreated seed, the percentage of kernels germinating increased progressively up to 25° C. but fell off at 30° C. However, any differences in germination of treated and untreated seed observed between different soil temperatures were not statistically significant.

TABLE 5.—PERCENTAGE GERMINATION IN TREATED AND NON-TREATED,
FRACTURED FLAX SEED PLANTED IN
FOUR DIFFERENT SOILS

Soil type	Seed treatment	
	Treated	Control
Brown, sandy loam	92.1	56.7
Grey-wooded loam	91.6	50.9
High-lime black loam	94.7	44.0
Black clay loam	93.8	39.0
Necessary difference (5% level)	3.24	3.24

TABLE 6.—PERCENTAGE GERMINATION IN FRACTURED FLAX SEED
SOWN IN BLACK, CLAY-LOAM SOIL HELD AT
5 DIFFERENT TEMPERATURES

Temperature	Seed treatment	
	Treated	Control
10° C.	94.5	44.7
15° C.	95.0	47.0
20° C.	97.5	49.7
25° C.	94.7	54.7
30° C.	96.7	50.0
Necessary difference (5% level)	D.N.S.*	D.N.S.

* D.N.S. = Differences not significant.

EFFECT OF THRESHING-INJURY ON SEED GERMINATION AND CROP YIELD UNDER FIELD CONDITIONS

In the majority of the Winnipeg experiments with flax, the percentage of seed germinating in the field was approximately the same as it was in the greenhouse, or it was somewhat higher. However, while a greenhouse test made at Winnipeg indicated fairly well how fractured flax seed would germinate under field conditions at Winnipeg, it did not necessarily indicate how the fractured seed would germinate under field conditions elsewhere. To determine what information regarding this point could be expected from a greenhouse test, 8 lots of Redwing flax, each containing a different percentage of fractured kernels, were planted in 1942 in the greenhouse at Winnipeg and at several experimental stations in Western Canada. The results from these trials are summarized in Table 7. They show that, at Winnipeg, as at most of the other stations, severely fractured flax seed germinated somewhat better in the field than it did in the greenhouse. The germination results were based on a comparison of the germination of

untreated, fractured seed with that of treated, uninjured seed, the latter being sown in plots in another part of the same experiment. The yield results were obtained in the same way, the yield of the plots sown with untreated, fractured seed being taken as a percentage of the yield of other plots sown with treated, uninjured seed.

The yield data from the field experiments just discussed were relatively inconclusive. Earlier (3), it was observed that moderate and severe fracturing of the seed definitely reduced the yield. In the present experiments, however, threshing-injury to the seed reduced the yield at some stations but not at others. An inspection of the plots at Winnipeg, Morden, and Brandon revealed that, in plots where there were thin stands of seedlings, the individual plants branched very freely. The result was that the yield from such plots was almost as large as the yield from plots with much denser stands of seedlings. Evidently, in plots with thin stands, the loss of seedlings resulting from seed fracturing was almost compensated for by increased branching of the surviving plants. It is not known how often such conditions occur in Western Canada, but it may be that crop losses from threshing-injury to the seed are generally less severe than indicated by earlier experiments (3).

TABLE 7.—GERMINATION OF UNTREATED, FRACTURED FLAX SEED IN NON-STERILE SOIL IN A GREENHOUSE IN RELATION TO ITS GERMINATION UNDER FIELD CONDITIONS AND TO THE SUBSEQUENT YIELD

Effect of kernel fracturing		Percentage of fractured kernels in seed							
		2	8	16	20	26	33	39	51
Germination in greenhouse, %		98	88	89	81	71	65	60	48
Germination in field plots, %*	Station								
	Winnipeg	94	96	87	88	82	82	85	65
	Morden	83	81	77	82	67	60	54	49
	Brandon	84	82	89	84	73	79	75	55
	Indian Head	100	100	100	100	100	100	97	83
	Melfort	81	80	92	84	80	81	68	63
	Swift Current	100	100	100	100	84	81	67	47
	Scott	—	—	—	—	—	—	—	—
	Lethbridge	98	93	91	94	79	77	76	54
	Lacombe	93	88	88	79	78	75	77	63
	Beaverlodge	89	91	81	75	71	77	72	56
	Mean of stations	91	90	89	87	79	79	74	59
Yield in field plots, %*	Winnipeg	100	98	99	100	98	96	96	93
	Morden	90	93	100	98	95	93	93	87
	Brandon	97	99	99	100	96	95	95	97
	Indian Head	100	76	96	100	100	100	100	82
	Melfort	100	96	100	100	100	96	93	90
	Swift Current	89	100	100	100	92	100	90	59
	Scott	91	81	99	77	86	100	77	71
	Lethbridge	84	87	86	88	89	79	87	85
	Lacombe	100	100	100	100	100	100	100	100
	Beaverlodge	92	100	98	97	100	81	94	89
	Mean of stations	94	94	97	96	95	94	92	85

* Germination of untreated, fractured flax seed in field plots and the subsequent yield expressed as a percentage of the average germination and yield in 6 plots in another part of each experiment but sown with treated, uninjured seed.

RESULTS FROM TREATMENT OF FRACTURED FLAX SEED

Comparison of Seed Disinfectants

Limitation of space in the greenhouse prevented a comparison of many seed disinfectants simultaneously on a large scale. On this account, a greenhouse test usually consisted of duplicate plantings made at different times. In the field, where more space was available, each treatment was replicated at least six times.

TABLE 8.—EFFECT OF DIFFERENT DOSAGES OF VARIOUS SEED DISINFECTANTS ON THE PERCENTAGE GERMINATION OF FRACTURED FLAX SEED UNDER GREENHOUSE AND FIELD CONDITIONS AND ON THE SUBSEQUENT YIELD IN FIELD PLOTS

Seed disinfectant	Dosage (oz. per bu.)	Germination, %						Yield‡, gm.		
		Greenhouse†			Field‡					
		1941	1942	1943	1941	1942	1943	1941	1942	1943
Control	0.0	56.6	45.0	43.0	167.5	262.1	249.0	111.4	218.0	91.2
N.I. Ceresan*	0.5	69.2	59.5	75.5	186.1	293.8	368.2	116.5	210.9	132.0
N.I. Ceresan*	1.0	—	84.5	93.5	—	367.0	372.5	—	202.2	112.7
N.I. Ceresan*	1.5	88.9	88.5	93.5	203.1	394.8	404.5	111.7	205.9	150.7
N.I. Ceresan*	2.0	—	91.0	91.5	—	306.8	397.7	—	209.5	129.7
Half-ounce Leytosan	0.5	58.7	47.0	59.5	183.1	293.5	299.0	114.7	210.7	116.7
Half-ounce Leytosan	1.0	—	50.5	73.0	—	278.3	345.0	—	196.1	126.7
Half-ounce Leytosan	1.5	76.4	76.5	75.0	202.1	306.8	345.7	125.0	208.1	108.5
Half-ounce Leytosan	2.0	—	75.0	89.0	—	319.0	355.0	—	196.6	135.5
Leytosan	1.0	64.0	—	—	174.0	—	—	113.1	—	—
Leytosan	4.0	77.5	—	—	197.0	—	—	113.3	—	—
Lunasan	0.5	52.0	—	—	178.4	—	—	113.8	—	—
Nomersan	7.0	64.5	—	—	185.9	—	—	112.4	—	—
Spergon	1.0	—	48.0	58.0	—	278.6	281.0	—	218.8	119.2
Spergon	2.0	—	41.0	61.5	—	271.5	309.2	—	205.0	110.7
Spergon	3.0	—	58.5	68.5	—	294.8	313.2	—	190.7	106.0
U.S.R. 601††	1.0	—	46.0	48.0	—	224.0	250.7	—	195.0	113.2
U.S.R. 601	2.0	—	39.5	48.0	—	266.6	220.5	—	203.2	104.0
U.S.R. 601	3.0	—	38.5	49.5	—	259.6	234.0	—	190.2	103.5
U.S.R. 604	1.0	—	73.0	68.5	—	266.1	371.7	—	190.5	117.7
U.S.R. 604	2.0	—	83.0	85.0	—	247.5	361.7	—	201.0	131.5
U.S.R. 604	3.0	—	82.0	85.0	—	245.6	356.0	—	195.9	114.0
Thiosan	0.5	—	45.5	—	—	203.8	—	—	195.5	—
Thiosan	1.0	—	47.5	80.0	—	255.1	352.2	—	203.3	114.7
Thiosan	1.5	—	57.0	—	—	264.8	—	—	207.9	—
Thiosan	2.0	—	65.0	87.0	—	279.0	341.5	—	209.2	118.0
Thiosan	3.0	—	—	89.0	—	—	280.7	—	—	91.2
Arasan	1.0	—	—	84.5	—	—	364.7	—	—	133.2
Arasan	2.0	—	—	91.0	—	—	402.2	—	—	121.0
Arasan	3.0	—	—	91.5	—	—	377.7	—	—	119.2
Necessary difference (5% level)		—	—	—	16.7	47.6	43.7	D.N.S.§	7.6	4.7

* New Improved Ceresan.

† Percentage germination (means of 2 replicates).

‡ Count of mature plants and yield in 10' 0" row.

§ D.N.S. = Differences not significant.

†† United States Rubber Co.

The results obtained from a comparison of different seed disinfectants, in respect to their effect on germination of fractured flax seed and the subsequent yield, are summarized in Table 8. These results indicate that New Improved Ceresan, Half-ounce Leytosan, Leytosan, U.S.R. 604, Thiosan, and Arasan satisfactorily prevented the rotting of fractured flax

seed in non-sterile soil in the greenhouse. Nomersan, Spergon, and U.S.R. 601 were less effective. Under the field conditions prevailing at Winnipeg in 1941, New Improved Ceresan, Half-ounce Leytosan, and Leytosan significantly increased the stand of plants but they failed to increase the yield. In 1942, New Improved Ceresan and Half-ounce Leytosan again significantly increased the stand of plants but failed to increase the yield, and in that year the plots sown with untreated seed yielded more than did the plots sown with seed treated with most of the disinfectants tried. In 1943, the stand of plants was significantly improved when the seed was treated with New Improved Ceresan, Half-ounce Leytosan, Spergon, U.S.R. 604, Thiosan, and Arasan; and the increases in density of stand were followed by increases in yield. The results from these experiments indicated that the two mercury-containing seed disinfectants, New Improved Ceresan and Half-ounce Leytosan, gave the best results when used at the rates of $1\frac{1}{2}$ oz. and 2 oz., respectively, per bushel of seed.

In addition to the experiments that were made at Winnipeg, field experiments with treated and untreated, fractured and sound flax seed were made at nine other stations in 1942 and at eight other stations in 1943. In each year, New Improved Ceresan was applied to the seed at

TABLE 9.—EFFECT OF TREATING SOUND AND FRACTURED FLAX SEED WITH NEW IMPROVED CERESAN (1.5 OZ. PER BU.) ON NUMBER OF PLANTS IN A 10 FT. ROW, AND ON THE RESULTING YIELD

Year	Station	Number of plants					Yield (gm.)				
		Sound seed		Injured seed		Necessary difference (5% level)	Sound seed		Injured seed		Necessary difference (5% level)
		Treated	Control	Treated	Control		Treated	Control	Treated	Control	
1942	Winnipeg	332	312	235	216	44.5	157	159	154	147	D.N.S.
	Morden	393	330	257	194	78.8	123	112	111	108	D.N.S.
	Brandon	379	319	285	208	D.N.S.*	143	139	144	138	D.N.S.
	Indian Head	437	468	399	361	D.N.S.*	166	169	146	136	24.6
	Melfort	350	285	313	220	D.N.S.*	119	119	116	108	D.N.S.
	Swift Current	64	81	79	30	22.4	81	72	88	48	D.N.S.
	Scott	—	—	—	—	—	107	98	95	77	D.N.S.
	Lethbridge	349	344	302	188	D.N.S.	203	171	163	173	D.N.S.
	Lacombe	412	386	291	261	D.N.S.	178	179	175	191	D.N.S.
	Beaverlodge	434	385	287	242	D.N.S.	266	246	260	236	D.N.S.
	Mean	350	323	272	213		154	146	145	136	
1943	Winnipeg	352	384	274	114	33.0	103	110	100	86	13.2
	Morden	291	322	212	165	31.4	90	98	85	91	D.N.S.
	Brandon	393	420	318	283	41.7	120	120	118	118	D.N.S.
	Indian Head	442	433	399	348	25.1	105	105	97	101	D.N.S.
	Melfort	418	387	364	288	D.N.S.	87	90	84	81	D.N.S.
	Swift Current	267	262	218	125	32.5	52	53	49	40	D.N.S.
	Scott	288	274	265	225	D.N.S.	76	79	90	77	D.N.S.
	Lethbridge	411	402	353	306	D.N.S.	154	143	146	140	D.N.S.
	Beaverlodge	343	328	246	156	27.6	100	102	88	73	8.8
	Mean	356	356	294	223		98	100	95	89	

* D.N.S. = Differences not significant.

the rate of $1\frac{1}{2}$ oz. to a bushel. It was found (Table 9) that, notwithstanding a considerable variability between stations and between plots at a station, there was a general tendency for this treatment to increase the stand of plots sown with fractured seed. In several of the trials, however, the increases were too small to be statistically significant. In all the trials, there was little or no increase in density of stand when the treatment was applied to uninjured seed. The experimental results regarding yields (Table 9) were even less conclusive. The plots sown with treated, fractured seed tended to yield more than those sown with untreated, but in most of the trials the difference was not statistically significant. In 1/100-acre plots (Table 10) treatment of flax seed with New Improved Ceresan increased, in 1941, the stand of plants and the yield in proportion to the degree of seed injury, but the increase was less at Winnipeg than at Morden. In 1942, however, when a similar experiment, but with other lots of seed, was carried on at Winnipeg, Morden, and Brandon, seed treatment neither increased the stand nor increased the yield.

Effect of Excessive Dosages of Seed Disinfectants

Preliminary experiments carried on in the greenhouse during 1941 showed that when an excess of New Improved Ceresan (all the dust the seed could retain) was added to the seed, germination of the seed was retarded, the seedlings frequently possessed enlarged cotyledonary leaves, and, in some seedlings, no other leaves were formed. When Half-ounce Leytosan was applied to the seed in excess, germination was not retarded, but the seedlings became somewhat chlorotic and the rate of growth in the post-seedling stage was reduced. It was subsequently found that the degree of chlorosis was proportional to the dosage of dust applied to the seed. Spergon, in excess, did not retard germination of the seed, but after the seedlings had formed a few leaves a peculiar cup-like structure developed at the apex of each plant. This malformation resulted apparently from a fusion of several embryonic leaves. It had no adverse effect on the plant, as the stem continued its growth through the cup. This post-seedling effect of Spergon has recently been described by Forsyth and Schuster (1).

TALBE 10.—EFFECT OF TREATING LOTS OF FLAX SEED, CONTAINING DIFFERENT PERCENTAGES OF FRACTURED KERNELS, WITH NEW IMPROVED CERESAN (1.5 OZ. PER BU.) ON THE STAND OF PLANTS AND THE YIELD IN 1/100 ACRE FIELD PLOTS

Year	Station	Increase in germination over untreated controls, %				Increase in yield over untreated controls, %			
		Lot 1	Lot 2	Lot 3	Lot 4	Lot 1	Lot 2	Lot 3	Lot 4
1941*	Laboratory	41.0	91.0	174.0	—	—	—	—	—
	Winnipeg	17.1	33.0	38.9	—	0.0	6.0	12.5	—
	Morden	38.0	85.0	92.2	—	20.0	33.5	45.5	—
1942	Laboratory	0.0	4.6	62.5	104.4	—	—	—	—
	Winnipeg	29.5	7.4	18.6	1.5	0.0	10.5	14.4	14.8
	Morden	55.8	0.0	97.2	0.0	2.0	4.0	2.6	0.0
	Brandon	13.8	13.8	5.4	9.2	2.9	2.5	0.0	0.0

* The seed used in 1941 was different from that used in 1942.

The effect of excess dosages of different seed disinfectants on germination and yield of flax under field conditions was studied in 1941 and 1942. New Improved Ceresan delayed seed germination and seedling growth, but seed treatment with Half-ounce Leytosan had no visible adverse effect. Seedlings arising from seed treated with Spergon developed apical cups, the stem internodes were lengthened, the branches developed a somewhat prostrate habit of growth, and blossoming was retarded by more than a week.

The experimental results given in Table 11 show that when an excess of undiluted New Improved Ceresan or Half-ounce Leytosan was applied to fractured seed of Redwing flax, the stand of plants in 1941 was less dense than when either dust was first diluted and then applied in excess to the seed. With Bison flax, an excess dosage of undiluted Half-ounce Leytosan reduced the stand of plants but a similar dosage of New Improved Ceresan did not; and, when the dusts were diluted, neither dust caused any harm to the seed. None of the dusts just mentioned had any effect on the yield. In 1942, when this experiment was repeated but only the variety Redwing was used, excess dosages of undiluted or diluted New Improved Ceresan and Half-ounce Leytosan, and undiluted Spergon, failed to affect either the stand or the yield.

TABLE 11.—EFFECT OF DIFFERENT DUST SEED DISINFECTANTS, APPLIED TO FRACTURED FLAX SEED IN EXCESS *, ON THE NUMBER OF PLANTS, IN A PLOT AND THEIR SUBSEQUENT YIELD

Disinfectant	Dilution†	1941				1942	
		Redwing		Bison		Redwing	
		No. of plants	Yield, gm.	No. of plants	Yield, gm.	No. of plants	Yield, gm.
Control	—	165	123	157	111	286	181
New Improved Ceresan	0	228	130	208	131	305	190
New Improved Ceresan	1-1	249	131	194	123	313	170
New Improved Ceresan	1-2	249	130	212	117	314	179
Half-ounce Leytosan	0	206	120	139	97	306	180
Half-ounce Leytosan	1-1	245	136	209	128	309	184
Half-ounce Leytosan	1-2	247	139	214	126	295	180
Spergon	0	—	—	—	—	302	184
Necessary difference, (5% level)		20.6	D.N.S.‡	20.6	D.N.S.	D.N.S.	D.N.S.

* Excess = maximum amount retained by seed.

† Dilution 1-1 = equal volumes of disinfectant and talc;

1-2 = 1 volume dust with 2 volumes of talc.

‡ D.N.S. = difference not significant.

Effect of Storage on Treated Flax Seed

The results of seed treatment experiments given earlier (Table 8), indicated that the optimum dosage for flax seed was $1\frac{1}{2}$ oz. per bushel with New Improved Ceresan and 2 oz. per bushel with Half-ounce Leytosan. These dosages were considerably larger than the dosages generally recommended by the manufacturer of the two respective dusts and it seemed advisable, therefore, to study the effect of storage on flax seed given these larger

dosages. In a preliminary experiment, sound seed of Redwing and Bison flax was treated with New Improved Ceresan and Half-ounce Leytosan at $1\frac{1}{2}$ oz. and 2 oz. per bushel, respectively. Each lot of treated seed, as well as one untreated lot of each variety, was then divided into three portions, one of which was put into a glass jar, another into an ordinary grocers paper bag, and the third into a woven cotton bag. The jars and bags were then closed and all were placed in a dark room at a temperature ranging from 50°C. to 70°C. Samples of the stored seed were removed at intervals and planted, in duplicate, in a bed of non-sterile soil. The results from this preliminary experiment are given in Table 12 and they show that neither a $1\frac{1}{2}$ oz. dosage of New Improved Ceresan nor a 2 oz dosage of Half-ounce Leytosan reduced germination of the sound seed, even after it was stored for 637 days in a sealed, glass container. Flax seed stored in paper or cloth bags appeared to lose some of its germinability, but the loss in treated seed could not be attributed to an overdose of either disinfectant.

TABLE 12.—EFFECT OF DIFFERENT KINDS AND LENGTHS OF STORAGE ON THE PERCENTAGE GERMINATION IN SOUND FLAX SEED TREATED WITH NEW IMPROVED CERESAN OR WITH HALF-OUNCE LEYTOSAN

Fungicide	Variety	Kind of Storage*	Duration of storage (days)						
			0	21	49	96	300	379	637
None	Redwing	A	92	92	96	95	94	88	97
		B	92	95	90	89	85	87	86
		C	92	97	93	94	95	87	86
	Bison	A	85	89	88	87	87	87	89
		B	88	82	84	81	79	88	82
		C	88	86	90	85	81	86	81
New Improved Ceresan†	Redwing	A	93	97	91	94	89	95	91
		B	97	91	95	91	93	90	89
		C	94	87	96	98	87	91	85
	Bison	A	87	92	85	90	90	89	92
		B	92	92	94	83	85	88	81
		C	89	86	87	89	96	90	91
Half-ounce Leytosan‡	Redwing	A	93	92	98	93	91	91	93
		B	90	91	94	93	87	83	86
		C	98	98	94	97	95	96	94
	Bison	A	88	81	86	88	86	84	90
		B	92	89	89	93	88	88	90
		C	92	89	92	89	88	88	78

* Storage A = sealed glass jar; B = paper bag; C = cloth bag.

† Applied at the rate of 1.5 oz. dust to a bu.

‡ Applied at the rate of 2.0 oz. dust to a bu.

In the spring of 1942, different seed disinfectants were applied to fractured seed of Bison flax and the several lots of treated seed, as well as one untreated lot, were put into glass jars which were sealed and placed in dark storage at room temperature. In the spring of 1943, these lots of stored seed were planted in the field, along with other lots of the same seed but treated shortly before sowing. The results from this experiment are given in Table 13. They show that when fractured seed was treated with

New Improved Ceresan, Half-ounce Leytosan, or Spergon, and then stored, some injury to the seed from the disinfectant resulted. The injury, however, was not severe enough to cause an appreciable reduction in yield. When flax seed was treated with U.S.R. 601, U.S.R. 604, and Thiosan, storage cause no injury whatever.

In 1942, a number of different lots of Redwing flax, each containing a different percentage of fractured kernels, were left untreated or were treated with New Improved Ceresan at the rate of $1\frac{1}{2}$ oz. per bushel. Each of these lots was then divided into a number of sub-lots which were placed in paper coin-envelopes. A set of treated and untreated sub-lots was sent to each of several experimental stations in Western Canada for planting. A survey of the data from these plantings showed (Figure 4) that in both the treated and the untreated seed the percentage of kernels germinating decreased as the percentage of them that were fractured increased. With treated seed, however, the percentage of kernels germinating was somewhat higher than with untreated seeds.

TABLE 13.—EFFECT OF STORAGE ON FRACTURED BISON FLAX SEED TREATED WITH VARIOUS DISINFECTANTS AND KEPT FOR ONE YEAR IN SEALED GLASS JARS AT ROOM TEMPERATURE

Fungicide	Dosage (oz. per bu.)	No. of plants in 10 ft. row		Yield, gm.	
		Seed A*	Seed B†	Seed A*	Seed B†
Control	0.0	141	138	140	136
New Improved Ceresan	0.5	229	201	155	145
New Improved Ceresan	1.0	224	289	152	152
New Improved Ceresan	1.5	276	317	166	156
New Improved Ceresan	2.0	260	329	155	157
Half-ounce Leytosan	0.5	224	197	152	144
Half-ounce Leytosan	1.0	169	189	149	143
Half-ounce Leytosan	1.5	215	247	158	159
Half-ounce Leytosan	2.0	238	227	144	147
Spergon	1.0	126	131	128	133
Spergon	2.0	155	174	131	146
Spergon	3.0	163	216	130	138
U.S.R. 601**	1.0	123	121	132	143
U.S.R. 601**	2.0	107	95	126	122
U.S.R. 601**	3.0	92	114	128	122
U.S.R. 604**	1.0	146	164	145	137
U.S.R. 604**	2.0	188	199	152	138
U.S.R. 604**	3.0	187	158	145	131
Thiosan	0.5	139	146	141	124
Thiosan	1.0	187	178	149	149
Thiosan	1.5	210	212	152	151
Thiosan	2.0	221	199	142	147
Necessary difference (5% level)††		55.4		19.1	
Mean		182	192	144	141
Necessary difference (5% level)		D.N.S.‡		D.N.S.	

* Seed treated in 1942 and sown in 1943.

† Seed treated in 1943 and sown in 1943.

** United States Rubber Co.

†† Applicable to any above pair of values.

‡ D.N.S. = Difference not significant.

The above situation is difficult to explain. In a greenhouse test made before the seed was sent out, all the lots of treated seed germinated alike, differences in severity of seed-fracturing notwithstanding. It was thought, at first, that the protectant on the seed had deteriorated to some extent. This belief arose as the result of observations on the behaviour of treated Laxton's Progress peas that had been kept in storage for some time. These peas, injured by threshing, had been treated at the rate of $1\frac{1}{2}$ oz. per bushel with New Improved Ceresan and were then stored in sealed glass jars or cloth bags for a period of ten months. At the end of this interval, the treated peas stored in sealed glass jars germinated 99% in non-sterile soil while those in cloth bags germinated only 15%. When, however, the latter lot of peas was treated again with New Improved Ceresan at the original rate, the percentage germination rose to 92%. The same result was obtained in each of several subsequent trials, and it suggested that New Improved Ceresan gradually lost its value as a seed protectant when exposed to air.

Later experiments with treated fractured flax seed failed to support the findings with peas. When treated and untreated flax seed was stored in sealed glass jars or in paper envelopes, and then after different intervals of time, some of the seed was removed and planted in non-sterile soil without additional treatment or after treatment (in some seed lots the second treatment) with New Improved Ceresan at the original rate, it was found (Table 14) that fractured flax seed suffered chemical injury after prolonged storage, but that there was no apparent decrease in the protection afforded by New Improved Ceresan to the seed.

TABLE 14.—EFFECT OF DIFFERENT INTERVALS OF STORAGE IN SEALED GLASS JARS AND PAPER COIN ENVELOPES ON THE PERCENTAGE GERMINATION OF TREATED AND UNTREATED FRACTURED FLAX SEED

Method of storage	Original treatment*	Additional treatment†	Storage interval (days)					
			0	12	25	51	98	342
Sealed jar	None	None	27.0	31.0	35.3	37.0	43.6	65.3
	None	New Imp. Ceresan	95.0	90.0	88.6	89.3	95.2	94.6
	New Imp. Ceresan	None	91.3	88.0	84.3	79.0	85.0	80.0
	New Imp. Ceresan	New Imp. Ceresan	91.6	91.0	84.6	74.0	86.8	74.6
Paper envelope	None	None	30.0	26.0	47.0	32.3	38.2	60.6
	None	New Imp. Ceresan	92.6	90.0	88.6	90.6	95.2	92.3
	New Imp. Ceresan	None	91.6	88.0	84.3	83.0	82.2	83.7
	New Imp. Ceresan	New Imp. Ceresan	95.0	82.7	87.0	84.0	86.9	81.3

* Dust applied at the rate of 1.5 oz. of dust to a bushel of seed.

† Dust applied at the rate used in previous treatment.

Although the above experiments with fractured peas and fractured flax seed yielded opposing results, it would seem that both results help to explain the situation (Figure 4) observed when treated flax seed was planted at different experimental stations in Western Canada. This situation could be the result either of a partial loss of protection afforded the seed by a disinfectant or an injury from the disinfectant to fractured seed. With a loss of protection, the percentage of kernels rotting in soil would increase with an increase in the percentage of fractured kernels;

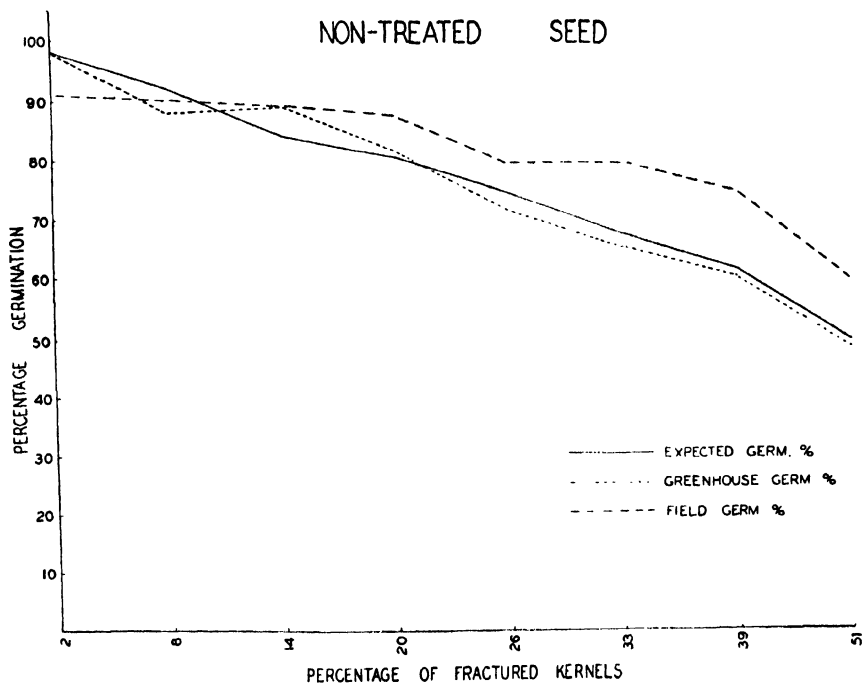
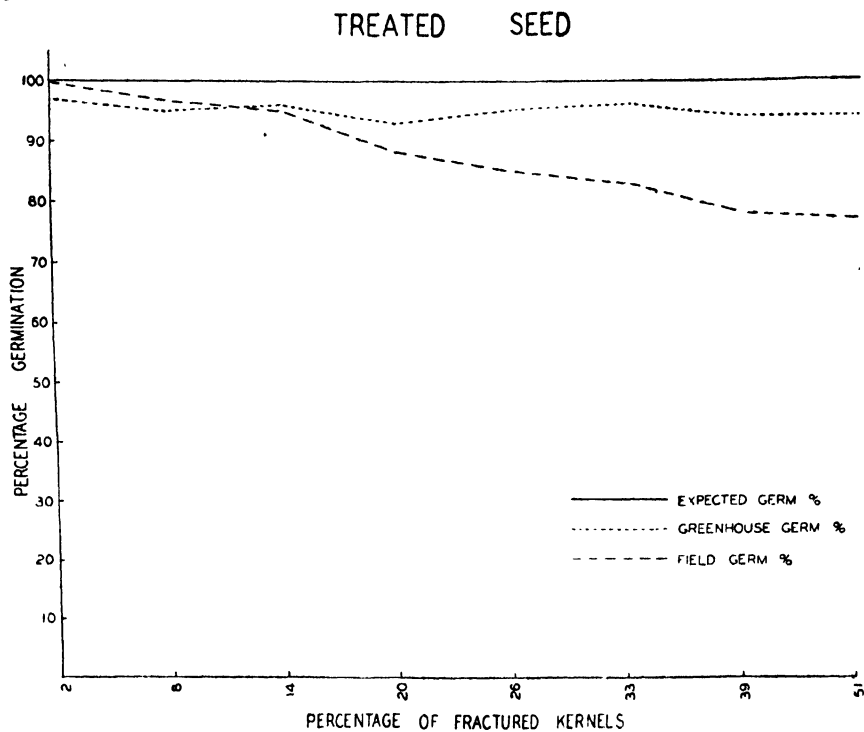


FIGURE 4. Relation of actual percentage germination in greenhouse and field to the expected germination. Above: treated seed. Below: non-treated seed.

while, with injury from the disinfectant, the percentage of seeds germinating would decrease with an increase in the percentage of fractured kernels. Possibly, both factors may operate simultaneously.

In passing, it may be worth while drawing attention to the fact that fractured flax seed appeared to become decreasingly susceptible to rotting in soil when such seed was stored for a period of time previous to planting. The experimental results (Table 14) with untreated seed stored in sealed glass jars show this tendency. It is suggested that, in fractured living kernels of flax, the exposed walls of fissures may, under suitable conditions of storage, gradually undergo a healing process through the development of cork or callus tissue. If this supposition is correct, soil-borne, seed-rotting organisms may be debarred entrance into the tissues of fractured kernels. The cotyledons are merely parts of a dormant plant, and possibly the development of protective wound tissue, such as occurs in wounded dormant tubers of the potato, actually takes place.

RELATION OF RATE OF SEEDING TO THE RESULTS OBTAINED FROM SEED TREATMENT

In Western Canada, flax has been sown at several rates of seeding, the rate generally being determined by the variety of flax used or by local conditions of soil and climate. These rates of seeding, ranging from 20 to 40 lb. to the acre, were established before threshing-injury to flax seed became recognized as a problem, and were, therefore, based on the results obtained locally with untreated seed. In view of the fact that seed treatment tended to increase the percentage germination in fractured flax seed, it seemed probable that treated flax seed would give satisfactory yields at rates of seeding lower than those used for untreated seed. To determine what these new rates of seeding actually were, several different lots of Redwing flax with a different percentage of fractured kernels in each lot were sown, treated and untreated, at Winnipeg in 1942 and 1943 at five different rates of seeding. The results of the experiment are given in Table 15. They show that the average yield of plots sown with the most severely fractured, untreated seed at the lowest rate of seeding, was not much below the average yield of plots sown with uninjured, treated seed sown at higher rates of seeding. As a matter of fact, seed treatment in this experiment could not be said to have increased the yield at all. An examination of the experimental data revealed a probable reason for this result. It was found that the number of plants, whether from treated or untreated seed, in a plot usually decreased with an increase in the percentage of fractured kernels in the seed. In plots sown with untreated seed, this decrease in the number of plants could be attributed to a rotting of fractured seed in soil, but, in the plots sown with treated seed, no rotting would take place, and, therefore, the reduction in the number of plants could be attributed only to a poisoning of fractured kernels by the fungicide. This toxic action of the fungicide evidently occurred in the interval (26 days) between treatment of the seed and the actual seeding, for, in greenhouse tests with freshly-treated seed, the most severely fractured seed germinated better than 90%. As a result of this progressive decrease in germination under field conditions, the difference in germination between treated and untreated seed was not sufficiently large at all the levels of seed fracturing studied to result in an observable difference in yield.

RECOMMENDATIONS GIVEN TO FARMERS REGARDING THE HANDLING OF THRESHING-INJURED SEED

During the course of this investigation, many samples of flax seed were received from farmers who wanted to know whether or not their flax seed was satisfactory for seed purposes. With the knowledge that seed treatment frequently improved the germination of seed in the soil, the writers set up a provisional classification based on the assumption that if 90% of the kernels in a sample germinated when planted in soil a satisfactory crop would result. Thus, for samples having a percentage germination of 90% or above, no treatment was deemed necessary. For samples which, after treatment, germinated below 90%, the usual rate of seeding was adjusted upward (see footnote under Table 16). For samples which germinated 90% or more when treated, and in which there was a gain of 20% or more in seed germination as the result of treatment, treatment of the seed with an organic mercury dust was recommended. Samples that, when treated, germinated less than 50% were regarded as unfit for seed purposes.

TABLE 15.—RELATION OF DIFFERENT RATES OF SEEDING AND OF DIFFERENT PERCENTAGES OF FRACTURED KERNELS IN THE SEED TO THE GERMINATION AND YIELD OF TREATED AND UNTREATED SEED OF REDWING FLAX

Rate of seeding (lb. per acre)	Fractured kernels, %	No. of plants per 10 ft. row				Yield, gm.				Yield increase from treatment, %	
		1942		1943		1942		1943		1942	1943
		Treat- ed	Con- trol	Treat- ed	Con- trol	Treat- ed	Con- trol	Treat- ed	Con- trol		
32	0	499	475	542	604	168	173	134	125	0	7
	20	406	405	547	493	156	166	136	130	0	4
	40	423	316	514	373	157	157	138	144	0	0
	60	366	286	491	324	156	156	116	130	0	0
28	0	458	403	546	524	162	151	141	127	7	11
	20	365	404	487	432	157	168	140	137	0	2
	40	363	310	451	339	167	163	131	153	2	0
	60	367	267	446	243	159	154	115	124	3	0
24	0	377	337	512	462	148	149	145	135	0	7
	20	408	313	461	398	168	154	134	145	16	0
	40	326	271	458	297	166	161	147	144	3	2
	60	275	243	380	234	148	148	136	127	0	7
20	0	326	345	386	353	146	156	130	141	0	0
	20	268	248	339	335	148	137	134	135	8	0
	40	277	243	339	243	161	151	141	135	7	4
	60	260	201	310	197	159	142	123	124	13	0
16	0	305	250	350	312	151	157	143	131	0	9
	20	258	217	337	217	138	148	134	135	0	0
	40	235	168	311	203	159	141	133	126	13	6
	60	198	182	280	148	148	136	110	113	9	0
Necessary difference (5% level)*		64.0		49.5		18.9		17.9		—	

* Applicable to any above pair of values.

In order to test the validity of the provisional classification just mentioned, 20 seed samples were taken from among those tested in the greenhouse, and, after the recommended adjustments were made, the seed was planted in the field at Winnipeg. One of these seed samples required no adjustment, 1 required an increase in the rate of seeding, 7 required treatment, and 11 required treatment and an increase in the rate of seeding. After the plants were harvested and threshed, the experimental data were examined to determine whether or not the original recommendations regarding the individual seed samples were justified. It was found (Table 16) that with all the seed samples used in the field test, except the one requiring no adjustment, the number of plants in a plot sown with adjusted seed was significantly greater than the number of plants in plots sown with unadjusted seed. A significant increase in yield was obtained, however, only in three (Nos. 9, 13, 16) of the 19 seed samples requiring adjustment, while, in 11 others the increase was not significant and, in the remaining 5 seed lots, there was no increase.

TABLE 16.—RESULTS FROM FIELD TESTS WITH SEED SAMPLES OF FLAX ADJUSTED IN THE WAY RECOMMENDED TO THE FARMERS IN ORDER TO COMPENSATE FOR KERNEL-FRACTURING OR NATURAL LOW GERMINABILITY OF THE SEED

Seed sample	Germination in greenhouse		Recommendations to farmers		Field results					
	Treat- ed	Control	Treat	Increase seeding rate by†	No. of plants in 10 ft. row			Yield (gm.) from 10 ft. row		
					Ad- justed	Control	Increase, %	Ad- justed	Control	Increase, %
				%						
1	95	59	Yes	0	297	184	61.4	155	138	12.3
2	92	65	Yes	0	319	249	28.1	148	166	0.0
3	95	74	Yes	0	353	276	27.8	87	106	0.0
4	70	35	Yes	43	321	120	167.5	131	114	14.9
5	96	56	Yes	0	405	224	80.8	124	105	18.0
6	92	60	Yes	0	284	206	37.8	140	142	0.0
7	84	44	Yes	19	332	152	118.4	147	146	0.6
8	87	54	Yes	15	401	228	75.8	97	93	4.3
9	77	59	Yes	30	356	131	171.7	142	113	25.6
10	80	67	Yes	25	402	165	143.6	139	133	4.5
11	88	78	Yes	13	367	173	112.1	156	144	8.3
12	97	97	No*	0	418	371	12.6	159	158	0.6
13	71	57	Yes	41	304	103	195.1	150	126	19.0
14	84	68	Yes	19	290	95	205.2	135	112	20.5
15	86	65	Yes	16	386	264	46.2	89	84	5.9
16	82	57	Yes	22	366	94	289.3	146	113	29.2
17	79	72	No	39	345	224	54.0	92	94	0.0
18	70	57	Yes	43	386	125	208.8	106	87	21.8
19	94	73	Yes	0	383	238	60.9	82	90	0.0
20	99	52	Yes	0	388	298	30.2	149	152	0.0
Necessary difference (5% level)‡					48.7	—	—	24.0	—	—

* This undamaged seed sample was treated even though it was sound, to provide a comparison with damaged seed lots.

† Percentage increase in rate of seeding = $\frac{\% \text{ kernels not germinating}}{\% \text{ kernels germinating}} \times 100$.

‡ Applicable to any above pair of values.

It is evident from the results of the above test that the provisional classification of flax seed samples was not set up on a practical basis. It appears, as other experimental results in this paper have indicated, that in Western Canada, flax seed of relatively low germinability may produce as high a yield as can seed of high germinability sown at the same rate. On this account, the provisional classification of seed samples probably should have been set up on the assumption that flax seed, germinating 75 or 70%, or less, can produce a satisfactory crop, providing that the rate of seeding remains at the present level. It is unreasonable to recommend to farmers that they treat their flax seed or increase the rate of seeding when the gain in density of stand is not sufficiently large to be followed by a gain in yield.

DISCUSSION

From the evidence given in this paper, it would appear that threshing-injury to flax seed is widespread in Western Canada and that, unless the seed is properly treated, lowered germination results. Other evidence indicates, however, that usually such lowered germination is seldom followed by reduced yields. Any one of two or more factors seems to be responsible for this situation. The prime factor seems to be the ability of flax plants in thin stands to branch freely. Thus, in a thin stand of plants, the production of seed bolls may be as great per unit area as in a denser stand where the individual plants, on account of competition for nutrients, branch less freely. In consequence, when two plots of flax differ in density of stand, because one was sown with sound seed and the other was sown with seed damaged by threshing, by an injurious fungicide, or by other factors reducing the percentage of kernels germinating, the difference in stand is not necessarily accompanied by a difference in yield. A secondary factor seems to be the tendency for farmers to sow flax at a rate high enough to offset low germination of the seed. On this account, when good seed or seed that has been improved by seed treatment is sown at the rate used ordinarily, more plants than can be adequately nourished are produced. Owing to severe competition, the plants yield individually less than they would if they were more widely spaced, and, therefore, the yield is not likely to be any greater than that from poorer and untreated seed sown at the same rate.

During the course of greenhouse and field experiments with flax seed treated with Spergon or Half-ounce Leytosan, it was observed that these materials, when applied in large dosages, affected flax seedlings in a way different from that when the seed was treated with a heavy dosage of New Improved Ceresan. With the latter material, germination of the seed was retarded and frequently the seedlings failed to develop other than cotyledonary leaves; but with Half-ounce Leytosan and Spergon, the effect of the treatment became visible only after the flax seedlings had developed several leaves, that is, at the post-seedling stage. Half-ounce Leytosan caused some chlorosis in the leaves and stems, while Spergon caused "freak" plant structures and a change in the habit of growth. It has been commonly believed that when a disinfectant is applied to seed the effect of the disinfectant is directly on the seed. The above observations regarding Half-ounce Leytosan and Spergon show that the influence of disinfectants applied to seed may be carried on to the seedlings. While,

with the two seed disinfectants just mentioned, treatment of the seed has an adverse effect on the resulting seedlings, it is possible that treatment of the seed with other materials may have an effect beneficial to the resulting plants. These plants, besides being improved in health, may acquire some characteristic increasing their productivity. It would seem that the post-seedling effect of seed disinfectants and other chemicals would be a subject of fruitful study.

Throughout this investigation, it was found difficult to account for marked variations in yield of flax from replicate plots, especially when these happened to be adjacent to each other. The experiments were ordinarily placed on apparently uniform blocks of land, but some unknown influence caused large differences in yield. Such variations in yield resulted in a large experimental error that frequently made differences between plots statistically insignificant. It is possible that increased replication or the use of another experimental design would have improved the situation.

In view of the fact that, in the majority of the present experiments, flax seed was sown in rows spaced 12 inches apart, the experimental results obtained here may not be applicable under the conditions of seeding on an ordinary farm. In actual practice, flax seed is drilled in rows that are 6 inches apart. Also, in experimental plots, weeds are generally not allowed to compete with crop plants while, on an ordinary farm, no attempt is made to destroy weeds except before the crop is planted. It is conceivable, therefore, that in experimental plots the development of flax plants would be much more luxuriant than under ordinary field conditions and that thin stands of plants, arising from damaged, untreated seed, would be more capable of giving a satisfactory yield. Thus, in experimental plots, a difference in the quality of seed may have no effect on the final yield, while, on the ordinary farm, where competition from weeds is allowed, flax plants in a thin stand may not be permitted to grow as well as they would if the field was free from weeds. On the ordinary farm, therefore, low quality seed would likely result in lowered yields, and high quality seed (providing a denser stand of plants and thereby withstanding competition from weeds) would likely result in satisfactory yields.

SUMMARY

In Canada, flax seed is often fractured when threshed during dry weather. This injury is much more common in Western Canada than in Eastern Canada. In some lots of seed, all the kernels may be fractured. The fractures are generally minute and invisible to the unaided eye, and, consequently, their presence does not affect the market grade of the seed. Large-seeded varieties of flax appear to be more subject than the small-seeded varieties to this type of injury.

When fractured flax kernels are planted in ordinary soil, many of them rot as a result of invasion by soil-borne micro-organisms. This rotting appears to be more frequent in heavy soils than in light soils, but the frequency of rotting does not seem to be affected by variation in soil temperature. When injured seed is planted under field conditions, the loss of plants from the rotting of fractured kernels is generally less severe than it is in the greenhouse.

Treatment of fractured kernels with suitable seed disinfectants prevents their decay in non-sterile soil. In heavy soils, New Improved Ceresan applied at the rate of $1\frac{1}{2}$ oz. per bushel gave the best result. In seed treated with New Improved Ceresan, prolonged storage may reduce the germination of fractured seed, but appears to cause no reduction in the germination of non-fractured seed. Treatment of flax seed with heavy dosages of Spergon may result in post-seedling damage to the plants.

While seed treatment generally improved the germination of fractured flax seed under experimental plot conditions, the improvement did not always result in improved yield. Similarly, when non-fractured seed was sown in the field, it germinated better than did fractured seed but the resulting yields were often at the same level.

ACKNOWLEDGMENT

The writers are greatly indebted to the Superintendents of the Dominion Experimental Farms and Stations in Western Canada for their generous co-operation in this investigation, particularly to Mr. A. W. Platt, Assistant in Agronomy, Experimental Station, Swift Current, Sask., for his continued interest and help. They acknowledge with thanks the kind assistance of the North-West Line Elevators Association, the United Grain Growers Ltd., the Manitoba Pool Elevators Ltd., the Manitoba Dept. of Agriculture, the officers of the Dominion Grain Inspection Division (Western Section), and the Supervisors of the Dominion Seed-Testing Laboratories at Winnipeg and Saskatoon in collecting the many samples of flax seed used during this investigation.

REFERENCES

1. FORSYTH, D. D. and M. L. SCHUSTER. Abnormal leaf formation on flax seedlings caused by Spergon. *J. Amer. Soc. Agron.* 35 : 733-735. 1943.
2. HÄRTEL, K. Über druschverletzten Lein und keimverletztes Getreide und ihre Beurteilung bei der Reinheitsbestimmung. *Compt. Rend. Assoc. Internat. d'Essais de Semences* 2 : 213-223. 1936.
3. MACHACEK, J. E. and A. M. BROWN. Preliminary investigations on mechanical injury in flax seed. *Phytopathology*, 26 : 733-734. 1942.
4. MACHACEK, J. E. and H. A. H. WALLACE. Non-sterile soil as a medium for tests of seed germination and seed-borne disease in cereals. *Can. J. Res. C*, 20 : 539-557. 1942.
5. MOORE, M. B. and J. J. CHRISTENSEN. Natural and mechanical injury in flax in relation to seed treatment (abstract). *Phytopathology*, 33 : 1117. 1943.
6. SCHUSTER, M. L., D. D. FORSYTH and J. G. HARRAR. Influence of certain diseases and threshing injury on flax stands in Washington. *Wash. Agr. Exper. Sta. V. Circ.* 8. 1943.
7. STEVENS, O. A. Germination studies on aged and injured seeds. *J. Agr. Res.* 51 : 1093-1106. 1935.

FIFTEEN YEARS EXPERIMENTS ON THE GRAY WOODED SOILS OF ALBERTA

By F. A. WYATT¹

University of Alberta, Edmonton, Alberta

[Received for publication March 20, 1945]

Wooded soils constitute one of the world's great soil groups and are found in all provinces of Canada. Practically the entire area east of the Great Lakes belongs to the wooded soil group. In the Prairie Provinces, the areas in the wooded soil group by far exceed the areas in the prairie soil groups. However, a much smaller proportion of the total wooded soils will be cropped than will be the percentage of cropped land in the prairie groups.

There are parts of the wooded soil areas in Ontario, Manitoba, Saskatchewan, Alberta, British Columbia and also in the North West Territories and in the Yukon that will be devoted to crops in the future. Alberta has a greater area of such soils than is found in any other province, and ultimately over 50% of all cropped lands in Alberta will belong to this group. For detailed descriptions of these soils, reference is made to Bulletin 21 (1), Circular 23 (2), and to some of the Soil Survey reports (3, 4). However, for convenience of the reader the following brief description might be adequate. These soils in Alberta belong to the gray wooded (northern podsollic) group and are characterized by the general profile descriptions:

Thickness of Horizon

- | | |
|----------|---|
| 0 - 4" | A ₀ moss to leaf mould; absent where fires have been severe. pH varies from 4 to 7 +, usually 5.5 to 6.8. |
| 0 - 4" | A ₁ mineral soil with varying amounts of organic matter; brownish to black platy. pH varies from 4.5 to 7 usually from 5.5 to 6.7. |
| 4 - 14" | A ₂ —average thickness 5 to 9", light gray to grayish brown, platy and ashlike. pH varies from 4.5 to 7, usually from 5.5 to 6.7. |
| 6 - 18" | B ₁ —average thickness about 12", light grayish brown to brownish (influenced by parent material) but usually darker than A ₂ , pH varies from 5 to 7, usually 5.5 to 6.8, granular to nutty. |
| 6 - 30" | B ₂ —average about 18", sometimes lighter in colour than B ₁ . Structures not so well defined as in B ₁ . pH varies from 5.5 to 7 +. |
| 18 - 60" | B _{ca} —below surface. |

When the virgin soils are first broken they have a very light gray appearance due to the exposed A₂ horizon. The furrow slice consists of A₀, A₁ and largely A₂ horizons. After several years of cultivation these horizons become mixed and the field then appears light grayish brown to light brown in colour. The pH of the cultivated fields (plow depth) varies from just over 5 to about 7. There is but little response to the application of lime and no difficulty is encountered in securing good stands of clovers and alfalfa, provided sulphur is applied when needed.

¹ Professor of Soils.

TABLE 1.—RANGE OF pH VALUES FOR SOILS FROM SOME OF THE BRETON PLOTS, SAMPLES COLLECTED 1940, 41 AND 44
Series A and C (Rotation)

Plot	1	2	3	4	5	6	7	8	9	10	11
Fertilizer applied	0	Manure	16-20-0 + K ₂ SO ₄	Amm. sulphate	0	Lime	Lime + triple super	Triple super	Manure 16-20-0	16-20-0	0
Depth 0 - 7"	5.7-6.6	5.9-6.9	5.2-6.5	5.4-6.6	5.9-7.0	6.9-7.5	7.0-7.7	5.9-7.3	6.2-7.3	5.4-6.9	5.9-7.0
7 - 18"	5.9-6.0	5.8-6.0	5.6-5.7	5.6-5.8	5.7-5.9	5.7-6.2	5.9-6.3	5.7-5.8	5.6-5.7	5.5-5.6	5.7-6.3
20 - 40"	5.9-6.0	5.7-6.0	5.5-5.9	5.6-5.8	5.8-6.0	5.6-5.9	5.7-6.0	5.6-5.7	5.6-5.7	5.5-5.6	5.8-5.9

Series E (Continuous wheat)

0 - 7"	6.6-6.7	6.8-6.9	6.5-6.6	6.5-6.6	7.0	7.4-7.5	7.5-7.6	7.0-7.1	7.2-7.3	6.6-6.9	6.4-7.0
7 - 18"	6.3-6.4	6.4	6.4	6.5	6.5	6.6-6.7	6.6-6.7	7.0	7.2	5.8-6.8	6.1-6.8
20 - 40"	6.0-6.1	6.0	6.2	5.8-5.9	6.1-6.2	5.9	6.1	6.4-6.5	6.6	5.6-6.0	5.6-6.0

A better idea of the range in pH values may be obtained by referring to the data from the plots from three of the series at Breton and reported in Table 1. These samples were collected from the same plots during three different years and in some instances at different intervals during the same years. The extreme ranges in pH values for the various plots are reported in the table. Here it is seen that the soil to the plow depth (0 to 7 inches) varies in pH values for the different samples collected. This variation is common to all plots and at times amounts to 1.5 pH units. The plow depth samples are generally just slightly acid ranging from just under 6 to just over 7 with the exception of plots 6 and 7 (limed) where the surface samples are at all times alkaline. There is no clear cut indications that any of the fertilizers (except lime) has influenced the pH values of the soils after 15 years of application (see Table 2 for annual rates).

The gray wooded soils of Alberta are found in the forested area. These forests consist chiefly of poplar, spruce, pine, willow, alder and tamarack, together with the common shrubs and sparse grasses. The rainfall over the greater part of the area varies from about 15 to 20 inches. However, the extreme northern part of the zone receives somewhat less rainfall, but even here there is generally a well developed soil profile in its upper horizons.

Any great expansion in the acreage of cropped land must of necessity take place on the wooded soils. Some of the problems involved in the future use of these wooded soils are:

(a) With proper management of these wooded soils, are they capable of producing satisfactory yields?

(b) What crops can and must they produce in order to maintain a satisfactory level of yields?

(c) How would extensive development of these soils affect the economy of Canadian agriculture?

(d) How would such development affect the health and wealth of the farming population?

(e) What would be the effect on land values?

The first two of the above questions can be definitely answered in the affirmative from our experiments on the wooded soils. The results from numerous co-operative experiments with individual farmers together with the results secured from the Breton Experimental plots during the past fifteen years show that, with proper management, it is possible to produce from 35 to 40 bushels of wheat, as the first crop after clover, from 60 to 80 bushels of oats as the second crop after clover, and from 25 to 35 bushels of barley as the third crop after clover. The clovers and alfalfa after being nursed with barley, yielded from $2\frac{1}{2}$ to 3 tons per acre on the best plots. The above yields were secured when adequate rotations and management were followed and were from 2 to 4 times the natural initial production from the soil without rotations and without fertilizers. Such yields as those secured above compare favourably with yields from the most productive sections of the black soil areas.

For purposes of reference, it might be well to show the cropping practices, the arrangement of plots, the kinds and amounts of fertilizers applied, and only the average yields secured from the Breton plots during the past five years (1940-44). These data are listed below in Tables 2, 3 and 4 without showing much of the detail actually involved in the practical farming operations. It is sufficient to say that any farmer occupying similar soils could carry out all the operations now performed on the Breton plots.

PLAN OF THE BRETON PLOTS

These plots are located about 70 miles south-west of Edmonton on typical wooded soil. The field contains about 20 acres of which 18 acres are in plots and the remainder is devoted to borders and roadways. The field was laid out in plots in 1930. Originally there were only 16 plots in each series but in 1938 an additional 10 plots were added to each series. Plot 12 is used as a roadway, while of the other 25 plots in each series, 7 are used as checks and 18 receive applications of various fertilizers (See Table 2). During the 15-year period (1930-44), 15 crops of wheat, 15 of oats, 22 of barley, 3 of flax, 2 of peas, 46 of clovers and alfalfa have been grown in sequence in addition to 12 crops of wheat on Series E (continuous wheat, one-half being cropped and the other half fallowed). With the exception of flax and peas all other crops have been produced annually and have been subjected to the individual seasonal effects of 15 consecutive years. Thus the average yields may be considered as fairly reliable.

The experimental field consists of 6 full series of 25 plots each in addition to 3 series with fewer plots. Each full plot is $1/11$ acre, being 30 ft. wide by 8 rods long. The total number of plots is just under 200. The series extend north and south and the plots east and west. The main rotation includes 5 series, illustrated as follows:

Series A—First year clovers (alfalfa and altaswede).

Series B—Second year clovers broken (the first cutting of hay is removed from the west half but the entire crop is plowed down on the east half).

Series C—Wheat—first crop after clovers.

Series D—Oats—second crop after clovers.

Series F—Barley—third crop after clovers (this crop nurses clovers to remain for next two years).

Series E is devoted to the continuous production of wheat, one-half being fallowed and the other half cropped each alternate year. Series G and H are used for the production of alfalfa and are only broken at intervals of 4 or 5 years. On several occasions flax, peas and barley have been grown after breaking alfalfa and clovers.

The crops are harvested and yields obtained from each plot and some half plots every year. Most of the crops are analyzed and graded annually. Baking tests for the wheat, malting tests for the barley, and oil content tests for the flax have also been determined.

The statement in Table 2 shows the plot arrangement together with the kinds and amounts of fertilizers applied annually during the last 5 years, the same periods for which yields are given in Tables 3 and 4.

TABLE 2.—FERTILIZERS APPLIED TO BRETON PLOT, 1940-44

Plot	Fertilizer	Average annual application, lb.				
		Fertilizers	Elements			
			N	P	K	S
1	None	—	—	—	—	—
2	*Manure	7 tons +	70	14	56	14
3	Complete {16-20 amm. phos. K_2SO_4	58 33	9	5	13	15
4	Ammonium sulphate	59	12	—	—	14
5	None	—	—	—	—	—
6	*Lime	325	—	—	—	—
7	{*Lime	325	—	—	—	—
	Triple super	62	—	10	—	2
8	Triple super	62	—	10	—	2
9	{*Manure} Amm. phos.	7 tons +	79	19	56	22
10	16-20 } amm. phos.	57 57	9	5	—	8
11	None	—	—	—	—	—
12	Roadway, permanent hay	—	—	—	—	—
13	None	—	—	—	—	—
14	11-48, amm. phos.	57	6	12	—	1
15	2-20, super phos.	92	2	8	—	8
16	0-20, super phos.	84	—	7	—	7
17	*Bone, phos.	257	10	25	—	3
18	None	—	—	—	—	—
19	Amm. nitrate	56	19	—	—	—
20	{Amm. nitrate	56	—	—	—	—
	*Gypsum	127	19	—	—	23
21	*Gypsum	127	—	—	—	23
22	None	—	—	—	—	—
23	Sod. sulphate	105	—	—	—	20
24	Pot. sulphate	77	—	—	—	15
25	{Pot. sulphate	83	—	—	—	—
	Amm. sulphate	60	12	—	33	31
26	None	—	—	—	—	—

* Most of the fertilizers are applied annually in a separate operation with the fertilizer attachment but not when the seed is being sown. However, manure, lime, bone and gypsum are applied at 3 to 5 times the above rates, but only at 3 to 5 year intervals.

During the earlier years the rates of fertilizers application were higher than indicated in Table 2, but as an average for the entire 15-year period the average annual rates were about 15% higher than for the the last 5-year period (1940-44).

When considering the yields in Table 3, it should be kept in mind that for Series E (continuous wheat) two years are required to produce each crop and that each crop has actually been fertilized during the fallow year and again during the crop year. Thus each plot in Series E receives the same amount of fertilizer as the corresponding plots in the other (rotation) series, but each half of Series E produces wheat only 50% of the time whereas some crop occupies the soil for the entire time in the rotation series.

We might be justified in dividing the yields shown for Series E by two before making direct comparison with the yields of wheat obtained when this crop was produced the first year after clovers.

The yields reported in Tables 3 and 4 are from seven series, each containing 25 plots. Eighteen plots in each series receives fertilizers of various kinds and amounts (see Table 2).

In the majority of cases (97%) the fertilizers have given increases in yields. Of the 126 fertilized plots only 4 show a minus sign and 3 of these are on Series E (continuous wheat). However, a number of the fertilizers have not proved to be efficient for these wooded soils and it is doubtful if such fertilizers as lime, triple super phosphate, bone, ammonium nitrate, will find an immediate general demand. From the standpoint of costs and efficiency for all crops, such fertilizers as ammonium sulphate, ammonium phosphate (16-20), single super phosphate and manure have given very good returns. Ammonium phosphate (16-20) supplemented with either potassium sulphate or manure has given the best all round results but the farmer cannot produce as much manure as we applied. Some of the other sulphur containing fertilizers were good for the legume hays but not so effective for the non-legumes. Most of them are fairly cheap but often they are difficult to apply.

TABLE 3.—AVERAGE GRAIN YIELDS AND INCREASES FROM THE BRETON EXPERIMENTAL PLOTS FOR THE 5-YEAR PERIOD 1940-44, INCLUSIVE

Plot	Fertilizer	Continuous wheat after fallow Ser. E, 5 yr.		(1) Wheat after clover 5 yr.		(2) Oats—2nd crop 4 yr.		(3) Barley—3rd crop 5 yr.	
		Yield	In-crease*	Yield	In-crease	Yield	In-crease	Yield	In-crease
1	None	17.1	—	12.9	—	25.8	—	13.0	—
2	M	29.2	12.7	32.8	19.0	58.0	30.7	25.1	12.6
3	16-20 + K ₂ SO ₄	24.5	8.6	35.2	20.5	77.6	48.8	27.0	15.0
4	Amm. sul.	22.8	7.5	36.5	20.9	66.5	36.2	24.1	12.6
5	None	14.6	—	16.6	—	31.8	—	11.0	—
6	Lime	19.0	3.7	16.9	0.0	36.7	3.4	14.5	2.7
7	1-triple	21.4	5.3	27.2	10.0	46.3	11.5	20.0	7.3
8	Triple	17.1	0.3	25.3	7.8	45.4	9.1	16.8	3.3
9	M + 16-20	35.5	17.9	41.4	23.6	84.9	47.1	36.6	22.2
10	16-20	26.0	8.6	32.9	14.9	70.0	30.7	28.0	12.8
11	None	19.1	—	18.3	—	40.9	—	16.2	—
13	None	32.9	—	25.8	—	50.5	—	20.7	—
14	11-48	38.0	5.3	32.5	7.3	71.8	21.9	27.2	5.1
15	2-20	36.4	3.9	38.3	13.7	59.3	10.0	26.7	3.2
16	0-20	41.4	8.8	40.6	16.5	70.3	21.6	36.6	11.7
17	Bone	37.7	5.6	30.0	6.3	61.3	13.2	27.2	0.8
18	None	31.8	—	23.1	—	47.6	—	27.8	—
19	Am. nitrate	36.3	3.0	26.4	1.0	56.1	9.6	27.9	0.7
20	Am. nitrate + gypsum	36.0	1.3	38.4	10.7	68.6	23.5	33.9	7.2
21	Gypsum	33.2	-3.1	39.4	9.3	51.8	8.0	32.5	6.6
22	None	37.7	—	32.5	—	42.6	—	25.3	—
23	Sod. sul.	34.9	-1.9	40.6	9.1	62.0	18.6	26.9	1.5
24	Pot. sul.	33.7	-2.1	42.4	11.8	56.2	12.0	27.2	1.5
25	Pot. sul + am. sul.	37.2	2.3	42.8	13.2	69.6	24.5	31.3	5.3
26	None	33.9	—	28.7	—	46.0	—	26.1	—

* Increase calculated by using sliding scale from check yields.

The Breton experiments leave many questions that are not answered:

- (a) What is the best way to produce legume seeds?
- (b) What is the best legume to be grown?
- (c) What is the best cereal to be grown?
- (d) What is the best mixture for hay as pasture?

They do supply the answers to many questions, such as:

- (1) Can satisfactory yields be produced every year?
- (2) Can the weeds be sufficiently controlled so as to almost eliminate the fallow practice?
- (3) What fertilizers and what rates are necessary?
- (4) Can high quality crops be produced?
- (5) Does proper management of these soils required the grain system or the livestock system of farming?

TABLE 4.—AVERAGE HAY YIELDS AND INCREASES FROM THE BRETON EXPERIMENTAL PLOTS FOR THE 5-YEAR PERIOD 1940-44, INCLUSIVE

Plot	Fertilizer	Clover, Average of 2 Series, 5 years		Alfalfa, 6 years	
		Yields, lb.	Increase*	Yields, lb.	Increase
1	None	806	—	900	—
2	M	2192	1380	1372	402
3	16-20 + K ₂ O ₄	5761	4943	5020	4070
4	Amm. sul.	5057	4223	4915	3985
5	None	831	—	910	—
6	Lime	1049	187	2066	1147
7	Lime + Triple	2375	1482	2352	1424
8	Triple	2185	1361	2110	1173
9	M + 16-20	6328	5373	5116	4170
10	16-20	6111	5121	5374	4419
11	None	1016	—	963	—
13	None	1000	—	1045	—
14	11-48	2675	1611	2379	1132
15	2-20	5649	4521	5026	3577
16	0-20	5362	4170	4520	2869
17	Bone	1914	658	2884	1031
18	None	1321	—	2054	—
19	Amm. nitrate	1551	-145	2161	37
20	Amm. nitrate + gypsum	4968	2897	5473	3279
21	Gypsum	4882	2436	5451	3191
22	None	2823	—	2331	—
23	Sod. sul.	4955	2144	5123	2811
24	Pot. sul.	4747	1748	5626	3339
25	Pot sul + amm. sul.	4742	1955	5473	3211
26	None	2775	—	2237	—

* Increase calculated by using sliding scale from check yields.

From Tables 3 and 4 the following facts are evident.

Legumes must constitute a fair proportion of the cropped area of the wooded soils (not less than 40 to 50%). This means livestock to provide a home market for pasture and hay crops.

Where required, proper fertilizers must be applied. These are more important for the legumes than for the grains or grasses.

Annual applications of from 40 to 60 lb. of such fertilizers as ammonium sulphate or ammonium phosphate (16-20) or the equivalent of some other satisfactory fertilizer such as single super phosphate (2-19) at 60 to 90 lb. should be adequate.

The greatest possible use should be made of all farm manure.

When the above practices are followed it should be possible to produce satisfactory yields of all crops common to the district. This is indicated by our yields of $2\frac{1}{2}$ to 3 tons of hay, 35 to 40 bu. of wheat, 60 to 80 bu. of oats, 25 to 35 bu. of barley.

Weeds can generally be controlled without the use of fallow, provided clovers and hay occupy the ground for two or more consecutive years and provided annual grain crops do not succeed each other for more than two or three consecutive years. For the control of certain of the perennial weeds it may be necessary to resort to the fallow.

The summary shown in Table 5 gives a general idea of the quality of wheat produced on the wooded soils. Data are reported for protein content, loaf volume, and acre yields from the rotation series and from the continuous wheat series prior to 1942.

The yield data are necessarily different from results shown in Table 3 since a different series of years are averaged. It is seen that as an average of all plots (fertilized and checks) the wheat following clovers has out-yielded the continuous wheat by 10.8 bu. This is the average value of clovers as indicated by increased wheat yields. The clovers on the unfertilized plots gave only 1.5 bu. increase whereas on some of the fertilized plots the increases ranged from approximately 10 to 17.5 bu.

In some of the co-operative experiments (not reported here) the protein content of wheat was as low as 7%. Most of the wheat grown by farmers on these wooded soils has protein contents varying from 7 to 10% and in general it is not grown following clovers. The wheat following clovers (Table 5) averages 13.2% protein while that from Series E averaged only 10.3%. The cropping practice (clovers in rotation) has had more effect upon the protein content than has the application of fertilizers. Wheat of high milling quality was not produced even when grown after clovers (average protein 13.2). This is shown by the data for loaf volume. The fact that some of the fertilizers increased the loaf volume (especially after clovers) does not mean that any of the plots yielded satisfactory milling wheat. Wheat, if grown on these soils, should be used as feed for livestock and should not be permitted to compete with high quality Canadian wheats.

Hays, oats, barley, flax of satisfactory quality can be produced. Grains should be largely fed to livestock on the farms in order to supplement the fodder consumed by livestock thus producing finished livestock and at the same time providing the greatest amount of farm manure. Barley of excellent malting quality can be produced. Certain of the legume seeds can be satisfactorily produced.

TABLE 5.—COMPARISON OF PROTEIN CONTENT, LOAF VOLUME AND YIELDS BETWEEN WHEAT GROWN AFTER CLOVERS AND WHEAT GROWN CONTINUOUSLY AT BRETON (PREVIOUS TO 1942)

	Checks	Manure	16-20 + K ₂ SO ₄	Amm. sulphate	Lime	Lime + Triple super phosphate	Triple super phosphate	Manure + 16-20	16-20	Average— All plots
Protein content of wheat (at 13.5% moisture)										
Wheat after clovers										
Average 12 years	13.4	12.2	12.6	13.8	13.6	12.9	13.1	13.0	13.6	13.2
Wheat continuous (Series E)										
Average 9 years	10.3	10.3	9.9	10.2	10.2	10.1	10.1	10.9	10.3	10.3
Rotation—Series E	3.1	1.9	2.7	3.6	3.4	2.8	3.0	2.1	3.3	2.9
Loaf volume cc. (baking tests)*										
Wheat after clovers										
Average 7 years	583	597	690	740	577	603	593	676	757	646
Wheat continuous (Series E)										
Average 5 years	516	516	519	566	496	517	481	610	563	532
Rotation—Series E	67	81	171	174	81	86	112	66	194	114
Wheat yields bu. per acre										
Wheat after clovers										
Average 12 years	14.5	25.1	33.5	29.3	17.9	23.4	21.7	34.5	32.1	25.8
Wheat continuous (Series E)										
Average 12 years	12.0	15.5	16.0	16.1	12.8	14.0	12.4	19.5	16.9	15.0
Rotation—Series E	1.5	9.6	17.5	13.2	5.1	9.4	9.3	15.0	15.2	10.8

* Baking data by Department of Field Crops.

• Baking data by Department of Field Crops.

The most urgent immediate problem retarding the development of the wooded soils is the cost of clearing and preparing the land for crops (5).

In order to maintain satisfactory yield levels it is necessary to follow mixed farming practices and include a good proportion of legumes.

Before the farmers on these wooded soils can generally become prosperous, adequate markets for livestock and livestock products at satisfactory price levels will have to be available.

Any extensive future settlement must, of necessity, be confined to the wooded soil area. This fact concerns every province and every citizen of Canada and will have a direct influence upon both our domestic and foreign markets. Immediate future settlement of some of these wooded soils must be considered in the rehabilitation scheme for many of the returned men from our armed forces.

ACKNOWLEDGMENT

During the past 20 years various members of the Department of Soils assisted in the field experiments, the laboratory work and the soils surveys that have made it possible to accumulate a vast mass of information regarding the wooded soils of Alberta. Only a part of this information—that dealing with the fertilizer experiments and crop responses—is reported in the present paper. Grateful acknowledgment is due to Dr. J. D. Newton, Dr. A. Leahey, Dr. V. Ignatieff, Dr. J. L. Doughty, Dr. R. E. Carlyle, Dr. A. C. Caldwell, Dr. T. H. Mather, Dr. E. Kneen, Messrs. A. S. Ward, R. E. McAllister, J. Kenwood and J. M. Bell for their contribution to the fertilizer experiments; to Messrs. W. E. Bowser, W. Odynsky, R. L. Erdman, Dr. O. R. Younge, N. Holowaychuk, A. D. Paul, H. J. Mather, T. W. Peters, F. R. Low and Dr. J. C. Hide for survey and analytical assistance; to Dr. A. G. McCalla, Messrs. G. Tosh and A. D. Paul of the Department of Field Crops for the milling and baking tests; and to members of the Dominion Grain Inspection staff for supplying grades for all grain samples.

REFERENCES

1. WYATT, F. A., J. D. NEWTON, V. IGNATIEFF et al. Wooded soils and their management. Univ. of Alberta, Bul. 21, third edition. July, 1941.
2. WYATT, F. A., J. D. NEWTON and V. IGNATIEFF. The use of fertilizers in Alberta. Univ. of Alberta, circ. 23, April, 1939.
3. WYATT, F. A. et al. Preliminary soil survey of Peace River-High Prairie-Sturgeon Lake area. Alberta Res. Coun. Rept. 31. April, 1935.
4. WYATT, F. A., J. D. NEWTON, W. E. BOWSER, W. ODYNSKY and J. A. ALLAN. Soil survey report of Wainwright and Vermilion sheets. Univ. of Alberta and Dom. Dept. Agr. Bul. 42. Sept., 1944.
5. ACTON, K. B. Use of power equipment in the improvement of Alberta bush lands. Dom. Dept. of Agr. Pub. 766—Farmers Bul. 127. Dec., 1944.

THE USE OF DISTILLERS', BREWERS' DRIED GRAINS, AND MALT SPROUTS FOR HORSES¹E. W. CRAMPTON²*Macdonald College, McGill University, P.Q.*

[Received for publication April 4, 1945]

Horse feeding is encumbered with numerous beliefs and prejudices which have in particular circumstances led to economically unsound feeding practices. One of the commonest of such beliefs in Eastern Canada holds that oats have special virtues; are irreplaceable by other feeds; and that rations which do not consist largely of oats are unsatisfactory, if indeed not unsafe, for horse feeding. The tenacity with which this trust in oats and distrust of other grains or grain by-products is held among practical horsemen is perhaps not surprising, when similar views appear to be held by those who have access to scientific literature, which without exception fails to support the oats superiority belief.

The Division of Animal Husbandry of the U.S. Bureau of Animal Industry says in *Food and Life*³ "Many horsemen consider that oats have no equal as a horse feed. This may be erroneous, however, as both experimental and practical feeding experience have shown that some other feeds, when properly combined may be either equal or superior to oats. . . . Most experiments have shown very little difference between the feeding values of corn and oats for work stock. . . . Barley is used as the principal grain for horses in many parts of the West. . . . Wheat, rye, rice, and some leguminous seeds are used as feed for horses under limited conditions." This excerpt is typical of the statements in recognized tests on horse feeding, and in no case is it the opinion of nutritionists that horse rations need contain any oats at all, or, any other specific feedstuff. Indeed it appears that the beliefs regarding the indispensability of oats in horse feeding are held chiefly in districts in which oats is the common farm grain raised.

While there is an abundance of evidence to the effect that horses may be fed a variety of different grains, the only by-product of grain about which there appears to be any extensive knowledge is wheat bran.

There are, however, three other grain by-products on the Canadian feed market, all of which are likely to be cheaper per ton than the coarse grains. The spread is especially marked with oats, for this grain in commercial feed channels in Eastern Canada is usually somewhat out of line in price with respect to its feeding value. These three by-products are brewers' dried grains, malt sprouts, and distillers' dried grains. The latter is a wheat by-product and the other two come from barley.

In terms of their "botanical" description, malt sprouts are actually the sprouts of barley which has been allowed to start germination. These sprouts or rootlets are removed when still very short. They are dried and

¹ Contribution from the Faculty of Agriculture, McGill University, Macdonald College, Que., Canada Journal Series No. 203.

² Professor of Animal Nutrition.

³ U.S.D.A. Yearbook 1939, pp. 763-786.

sold as a feedstuff. Brewers' and distillers' dried grains are almost analogous products from barley and wheat, respectively, at least in the sense that the chief portion of the original grain removed in the process leading to their production is starch. Roughly we have then in these two feeds, barley or wheat minus most of their original starch filling.

Chemically and nutritionally there are other differences between the entire grain and these two by-products. Several other nutrients which are water soluble may have been removed and not returned to the dried grains. And the loss of easily soluble nutrients will also mean that the nutrients remaining may be correspondingly of lower digestibility for species other than herbivora. For horses this latter is probably of minor significance. It seems certain that in the case of herbivora the cellulose and hemicellulose fractions of these feeds can be as well utilized as in roughage. And it is further known that herbivora appear to digest these complex carbohydrates about as completely as they do protein or ether extract.

All three of these by-products, however, are classed as high protein feeds. They contain about twice the protein found in the original grains due entirely to the fact that a non-protein material has been removed. The comparison of these by-products with their original grains and with oats is partly indicated in Table 1.

TABLE 1.—PARTIAL CHEMICAL COMPOSITION OF BARLEY AND WHEAT AND THEIR BY-PRODUCTS AS COMPARED TO OATS

Fraction	Barley	Brewers' dried grains	Malt sprouts	Wheat	Distillers' dried grains	Oats
Protein	12.8	20.7	28.1	12.0	24.0	12.5
Ether extract	2.3	7.2	1.8	2.0	6.1	4.4
Crude fibre	5.5	17.6	13.3	2.0	13.1	11.2
Non-fibre carbohydrate	67.0	42.5	43.4	71.6	45.0	60.7
Calcium	.07	.16	.26	.05	—	.10
Phosphorous	.32	.47	.68	.38	—	—

The fact that these by-products carry 20% or more of crude protein is very likely one reason they have usually been considered only as supplementary feeds-- products to be used to increase the protein content of mixtures of cereal grains (as in cattle rations). Such products as the oil-meals have normally been appreciably more costly in Canada than low protein basal feeds. This has naturally led to the usual recommendations to use high protein feeds in minimum amounts consistent with adequate protein levels in the final ration. Thus brewers' grains, distillers' grains and malt sprouts, falling into the classification of protein supplements, have not been looked on as products to be used primarily for energy.

There is no evidence, however, that feeding more protein than bare minimum is harmful. Indeed surveys show that training table diets for football players often contain 25% protein, and all herbivorous animals while at pasture consume diets running up to 30% protein when calculated to an air-dry basis. When animals consume a surplus of protein, the extra is used for energy in the same way that carbohydrate is, and yields approximately the same number of calories of metabolizable energy per gram as does carbohydrate.

With these facts in mind, viz., that both fibre and non-fibre carbohydrates are well digested by herbivorous animals, and that surplus protein is an acceptable source of energy, the comparison of the total of the digestible nutrients between the feeds of Table 1 is interesting.

Feed	Total digestible nutrients
Barley	77%
Brewers' grains	68
Malt sprouts	71
Wheat	76
Distillers' grains (wheat)	80*
Oats	72

* Estimate.

These figures might lead to the conclusion that any one of these feeds would be as good as oats as a source of energy, and there can be no doubt as to the adequacy of protein when oats is considered to contain enough of this material for work-horse feeding.

Experimental evidence, on the other hand, appears to be entirely lacking on the feeding value of malt sprouts and of wheat distillers' grains for horses, while only two experiments were found in which brewers' dried grains were compared to oats. These were summarized by the conclusion that "when cheap in price they may be used economically for half the oats in feeding work-horses—equalling oats pound for pound in feeding value." In a third trial brewers' dried grains were reported to be constipating to horses.

Somewhat aside from the matter of the supply of nutrients, there is the problem of the physical nature of feeds intended for horse feeding. It is well known that injudicious feeding practices may result in digestive disturbances such as "colic." It is the danger of colic that leads many horsemen to avoid heavy grains such as corn or wheat. Indeed, oats, because of its hull, is considered as a safer feed than the heavier grains. The bulkiness of oats is reflected in its fibre content of 11%. Reference to Table 1 indicates that taking oats as a standard, all three of the by-products, malt sprouts, brewers' grain, and distillers' grain, carry sufficient fibre to insure freedom from digestive troubles traceable to heavy, compact feeds.

Prompted in part by the absolute scarcity and relative high prices of oats at the time, and in part by the belief that a horse is no more demanding in its feed needs than a dairy cow, a series of observational tests was started in the fall of 1943 in which it was planned to feed farm horses, which had for years been accustomed to oats, on rations composed of their usual hay allowance plus either wheat distillers' dried grains, or brewers' dried grains or dried malt sprouts.⁴ The horses were to be managed in accordance with the needs for work to be done.

They were to be weighed about twice a month and the allowances of the oat substitutes adjusted to keep the animals at constant live weights.

⁴ These feeds were very kindly supplied by Distillers' Corporation Limited, National Breweries Limited, and Canada Malting Company, respectively.

From November 13, 1943 to the following April 23, 1944, six horses were available for the test. A second trial was carried out between June 1, 1944 and November 1, 1944, involving 13 animals, and is described later.

Table 2 summarizes the pertinent facts about these horses as at the time they were put on their respective trials.

TABLE 2.—DESCRIPTION OF HORSES USED IN OAT-SUBSTITUTE FEEDING TESTS

Stable	Name	Av. daily		Initial weight	Description
		Hay	Oats		
		lbs.	lbs.	lbs.	
1	Rivolette	12	13.5	1750	Percheron mare—fat—good feeder.
	Jack	12	12.0	1600	Clyde gelding—high strung, nervous temperament—fussy feeder—never fat.
	George	—	13.5	1600	Clyde gelding—good feeder.
	Colt	—	13.0	1565	Clyde gelding—quiet disposition—good feeder.
	Chief	6	8.0	1120	Thoroughbred gelding—quiet—not a heavy feeder.
	Nimble	6	6.0	1070	Standard-bred mare—nervous—good feeder.
2	Cockatoo	8	5.0	1080	Morgan mare—quiet—good feeder—easy keeper.
	Chips	8	5.5	1050	Morgan-type gelding—quiet—good feeder (in particularly poor flesh at the start).
3	Doll	—	8.2	1500	French Canadian mare—fat—good feeder.
	Charlie	—	7.7	1450	French Canadian gelding—fat—fair feeder.
4	Pearl	—	13.7	1500	Percheron mare—fat—fussy feeder.
	Pete	—	14.5	1375	French Canadian gelding—fat—indifferent feeder.
	Grayson	—	13.5	1375	Percheron-type gelding—fat—poor feeder.
	Jess	—	13.7	1260	French-Canadian mare—fat—good feeder.

TRIAL I

In Stable No. 1 were four horses used in Trial I. They were individually quite different. Rivolette was an exceptionally easy keeper, and in addition was a greedy feeder, while Jack was a tall, raw-boned horse that was temperamental about his feed and his surrounding. He always questioned changes in feed and frequently had to be coaxed to eat his full allowances. Chief and Nimble differed particularly as to hay consumption. Chief would eat only the fine parts of his hay while Nimble ate not only her hay but also much of her bedding. She kept fat while the gelding stayed in good condition but never seemed to put on much extra weight.

Cockatoo and Chips, used in both tests, were both very quiet, chunky types and maintained their weights on a minimum of feed.

For the first period of the trial these six horses were transferred over a period of two weeks from the ration of oats previously fed to equal allowances by weight of a mixture of 99% dried brewers' grains and 1% fine salt.

Jack questioned the new feed for two or three days and during the first two weeks on the straight brewers' grains both Rivolette and Jack were rather fussy feeders. Their daily allowances were not eaten promptly but were cleaned up before the next morning.

Live weights recorded after the first two weeks on the brewers' grains showed that Rivolette had gained 100 pounds, Cockatoo had lost some 70 pounds. Their actual measured feed consumption was found to be less in most cases than had been arranged for due doubtless to the feeder's unfamiliarity with the bulkiness of the product. (To obtain feed records each horse was provided with a separate feed bin into which weighed amounts of feed were put as needed. Actual feeding was done by measure. At the end of a given period (usually two weeks) the feed remaining in the bin was weighed and the horse charged with the quantity of feed which had been removed).

Following the first weighing Rivolette's feed was reduced by some two pounds per day, while that for Cockatoo and Chips was increased about half a pound daily. With these adjustments, allowances were satisfactorily eaten throughout the test.

The feeding of dried brewers' grains was continued for 42 days (until January 2, 1945). The summary of the live weights and feed records are shown in Table 3.

TABLE 3.—LIVE WEIGHTS AND FEED CONSUMPTION RECORDS OF HORSES ON BREWERS' GRAINS

Horse	Live weights		Gain 42 days	Average daily feed	
	Nov. 21	Jan. 2		Brewers' grains	Hay*
			lbs.	lbs.	lbs.
Rivolette	1750	1760	10	11	12
Jack	1600	1590	-10	10	12
Chief	1120	1140	20	6.5	6
Nimble	1070	1060	-10	5.5	6
Cockatoo	1080	1060	-20	5.5	8
Chips	1050	1080	30	5.5	8

* Estimated from periodic weighings.

During this period none of these horses were worked. Feces were entirely normal throughout the period and no evidence of leg swelling was found. Hair coats were in excellent condition.

Apparently daily allowances of 5 to 6 pounds of brewers' dried grains and 6 to 7.5 pounds of timothy hay per 1000 pounds body weight were adequate for winter maintenance feed.

Malt Sprouts

At the end of the first feeding test, all six horses were transferred from brewers' grains to malt sprouts. This feed has a rather pronounced taste and aroma and even though at the start a mixture consisting of 25% brewers' grains, 25% oats, and 50% malt sprouts was used, the four horses

of Stable No. 1 refused the feed for about two days. When the day's feed for each horse was moistened with about a quart of water containing one-third pint of molasses it was readily eaten.

After a week's time, straight malt sprouts (containing 1% salt) replaced the mixture of grains. It was necessary, however, to continue for another week the use of small amounts of molasses in Stable No. 1 to ensure the consumption of the full allowance. Cockatoo and Chips (Stable No. 2) never objected to the malt sprouts and ate well throughout the 6 weeks period.

On January 6, Rivolette, following a chilling in a trip to the blacksmith, developed colic. An aloes ball was given her. Manure passed was normal and there was no evidence of impaction. Regular feed was withheld until January 10. Jack consistently refused to eat his full feed allowance though working regularly during this period. Other horses were idle. On February 13 the malt sprout feeding was discontinued. The record of live weights and feed consumption during the period are shown in Table 4.

TABLE 4.—LIVE WEIGHTS AND FEED CONSUMPTION RECORDS OF HORSES ON MALT SPROUTS

Horse	Live weights		Gain 42 days	Average daily feed	
	Jan. 2	Feb. 13		Malt sprouts	Hay
			lbs.	lbs.	lbs.
Rivolette	1760	1880	120	10.6†	12
Jack	1590	1520	—70	12.2	12
Chief	1140	1110	—30	6.4	8
Nimble	1060	1070	10	6.4	8
Cockatoo	1060	—*	—	6.0	8
Chips	1080	—*	—	6.0	8

* Not weighed due to ice and snow conditions.

† For 35 days only, and including molasses when used.

Regardless of the gains or losses in liveweight which occurred while on this feed, it was evident that *the acceptableness of malt sprouts must be regarded as uncertain and unpredictable*, depending on the individual likes and dislikes of the horses.

Distillers' Dried Grains (Wheat)

On February 13, the horses in Stables No. 1 and No. 2 were started on distillers' dried grains. The change from malt sprouts was made abruptly. In view of the gains made by Rivolette during the previous period, and her already over-fat condition, she was started out on an allowance of 9 pounds daily—a reduction of about 2 pounds per day from the previous period.

All horses accepted the wheat distillers' grains without question. Rivolette, however, was put to work and as a result lost about 90 pounds in the first two weeks. Her ration accordingly was raised to 12 pounds per day.

On about March 1, a change was made in the hay fed in Stable No. 1. A coarser, poorer quality product replaced the good quality timothy fed up to that date. This was at once reflected in a lower consumption and in obvious wastage, and in a drop in the weights of all horses. On restoration of good quality hay plus a temporary increase in the allowances of the grains, most of the lost weight was regained. In Stable No. 2 the quality of the hay was especially poor all through this period.

The six horses were carried for 70 days on the distillers' dried grains. No undesirable conditions were noted with respect to condition of legs or of manure. The feed appeared to be acceptable as the entire grain portion of the ration. The records for the 70-day period are given in Table 5.

TABLE 5.—LIVE WEIGHTS AND FEED CONSUMPTION RECORDS OF HORSES ON WHEAT DISTILLERS' GRAINS

Horse	Live weight		Gain 70 days	Average daily feed	
	Feb. 13	Apr. 23		Distillers' grains	Hay
			lbs.	lbs.	lbs.
Rivolette	1880	1860	—20	11.7	12
Jack	1520	1540	20	13.1	12
Chief	1110	1070	—40	8.0	6
Nimble	1070	1050	—20	7.4	8
Cockatoo	1060*	1060	—	6.1	7
Chips	1080*	1080	—	6.1	7

* Weight, January 2, 1944.

In considering the actual changes in body weights of these horses, it should be noted that the period covered is 70 days while those for the malt sprouts and brewers' grains were but 42 days each. If these changes are real, i.e., to be charged to feed and not to the variations in single weights resulting from defecation or watering, etc., then they should be reduced by 40% to be comparable to those of the 42-day tests. Observation of the horses did not lead to the conclusion that they were changing weight appreciably over the period as a whole.

Concerning the distillers' grains; it proved to be *an acceptable oat substitute for winter feeding of horses who were worked only occasionally* but were for the most part idle.

General Results of the Winter Feeding Tests

Taking the 154-day feeding period as a whole, there was no evidence, save for the lack of palatability of the malt sprouts, that the nutritive value of these feeds differed from oats or from each other when they formed the entire non-roughage feed of the horse. No cases of swollen legs were found nor any evidence of digestive disturbances. Those individuals that did not object to the malt sprouts did well on it.

The weight changes over the whole period are interesting.

TABLE 6.—WEIGHTS OF HORSES AT START AND END OF WINTER FEEDING

Horse	Nov 21	Apr. 23	Weight change
Rivolette	1750	1860	+110
Jack	1600	1540	— 60
Chief	1120	1070	— 50
Nimble	1070	1050	— 20
Cockatoo	1080	1060	— 20
Chips	1050	1080	+ 30
Average per horse			1.7 lbs.

In connection with these figures it may be noted that Jack and Chief undoubtedly really lost weight during the winter. Chief had just come to the stable at the opening of the test. He had been on pasture during the summer and then on an allowance of 8 to 10 pounds of oats plus unlimited hay in his former stable. He had shown a little difficulty in eating and his previous owner had been unsuccessful in having dental work done on him. It was partly for this reason that he became available for these tests. The use of ground feed proved advantageous and he maintained his weight until the coarser hay was introduced, of which he refused considerable portions.

Jack on the other hand proved to be temperamental in his feeding as well as in his behaviour. He had never been an easy keeper on any feed. For him the wheat distillers' grains were more satisfactory than either of the other feeds.

For winter feeding of nearly-idle horses, the kind of hay available is undoubtedly an important factor in determining the amounts of grain feed needed to maintain a given condition of live weight.

TRIAL II

Summer Feeding

The first series of tests gave no information relative to the value of any of these products for horses at work—where the energy of the ration would be a greater factor and therefore where palatability might determine the limits to which the feeds could be used.

For the second series of trials some changes were made in the horses used. Jack was omitted largely because he was giving his driver some difficulty, and was generally unsuited to feed testing work. Two others from the same stable, George, a mature clyde gelding and an unnamed three-year old clyde colt, were chosen along with Rivolette and the two light horses, Chief and Nimble. Chips and Cockatoo from Stable No. 2 were not available until July 1. Six additional horses from Stables Nos. 3 and 4 were also used. The general plan of feeding was the same as in the previous periods except that no record was made of hay consumption. This was partly due to the fact that some of the teams had access to pasture, nights and weekends.

Malt sprouts was omitted as the results during series 1 indicated that one of its limiting factors was palatability. It was also decided to divide

the horses into two groups—one to be fed continuously on brewers' grains and the other on wheat distillers' grains. Salt was to be fed individually to each horse.

All horses were started during the first week in May on a mixture of equal parts of crushed oats and brewers' dried grains. On June 1 the horses in Stables No. 1 and No. 2 were changed to straight wheat distillers' grains; those in Stables No. 3 and No. 4 to brewers' dried grains.

The main feeding period continued through August, though the two horses in Stable No. 2 and the pair in Stable No. 3 were left on their respective rations through October. Weighing was done approximately at fortnightly intervals but this was not strictly adhered to because of summer work schedules. For purposes of this report all weighings in a given calendar month were averaged and taken as the average weight of the horse during that month. No unusual fluctuations were found in adjacent weighings and the average figures appear to give a true picture of the success in adjusting feed allowances to maintain the horses in constant live weight.

In Table 7 are summarized the average monthly weight of the horses and their average daily intakes of brewers' grains or distillers' grains.

TABLE 7.—WEIGHTS OF HORSES AND FEED CONSUMPTION RECORDS—TRIAL II

Feed	Horse	June		July		August	
		Weight	Feed	Weight	Feed	Weight	Feed
Wheat distillers' grains	Rivolette	1850	11.0	1840	15.0	1840	11.5
	George	1600	13.5	1550	15.2	1570	11.0
	Colt	1565	13.3	1560	15.4	1530	10.7
	Chief	1110	8.3	1100	10.4	1090	8.9
	Nimble	1075	8.3	1100	11.3	1100	6.7
	Chips	—	—	1040	5.0	1020	5.0
	Cockatoo	—	—	1015	5.0	1000	5.0
Brewers' dried grains	Doll	1500	8.2	1540	7.4	1500	8.1
	Charlie	1450	7.7	1450	7.9	1465	7.5
	Pearl	1500	13.7	1530	11.0	1550	10.7
	Pete	1375	14.5	1390	12.0	1400	11.7
	Jess	1260	13.7	1300	12.0	1315	10.7
	Grayson	1375	13.5	1375	12.0	1375	10.7

Because of varying work schedules it is impossible to compare directly the quantities of feed needed per unit of live weight of animal in these tests. From the data of Table 7 and the observations made during the test some results may warrant specific note.

(1) There was no evidence that more than one pound of grain need be fed per 100 pounds of live weight of horse even when the animals are at farm work.

(2) Horses differ considerably in their feed requirements per unit of their weight depending on their individuality more than on their weight. This is doubtless influenced also by their hay consumption. Horses willingly eating liberal amounts of good quality hay need much less grain than those whose hay intake for one reason or another is low.

(3) There was no difficulty in getting any of the horses to eat enough of the brewers' or distillers' grains to maintain their live weights, hay being fed in amounts readily cleaned up. Night pasturing appeared to save hay, but not grain. It may also be noted that while horses were not at work, they would frequently refuse to eat the full "work allowance" of the brewers' grains. Thus it might be found that these feeds could not easily be used for fattening horses as for show or for sale unless mixed with more palatable feeds.

(4) No adverse effect of either of these feeds was found at any time during the trials. Hair coats remained in good condition; no digestive disturbances occurred; and no leg trouble was experienced.

Though not a part of these tests, it may be of interest that six of these horses have continued for all or a part of the past winter on one or other of these feeds as the only grain used. Results have been entirely satisfactory.

CONCLUSIONS

To the extent that they can be drawn for observational tests of this kind, the following conclusions relative to the usefulness for horse feeding of brewers' dried grains, distillers' dried grains (from wheat), and malt sprouts appear to be warranted.

Malt Sprouts, probably because of a characteristic and pronounced aroma may be refused by some horses if used as the entire ration other than hay. If diluted with an equal weight of some other feed, as ground oats, it will probably be readily eaten. For those horses who do not object to it, this feed has proved satisfactory.

Brewers' Dried Grains, have been found approximately equal to oats as a work horse feed, on the basis that when used as the entire grain portion of the ration no larger allowances were needed to keep horses in constant body weight than had been needed of oats. In general this feed, if not offered in amounts in excess of those needed to maintain body weight, will be satisfactorily eaten by work horses. Some horses, however, may not readily clean up greater allowances than this, which might limit the usefulness of brewers' grains in fattening or fitting rations. When mixed with oats, this limitation was not apparent.

Distillers' Dried Grains (from wheat). This by-product appeared to be equal to oats under the conditions of this test. It may be noted that for one very hot week during July, the three draft horses in Stable No. 1 were on especially heavy work. As a consequence they lost considerable weight (about 50 pounds). Rather than increase the feed allowance, 20% barley was added to the distillers' grains to increase its weight per quart. Within two weeks the lost weight had been recovered, and during the next month the feed allowances were reduced as seen in Table 7. Distillers' grains were readily eaten as the sole grain allowance. The maximum offered was 1 pound per 100 pounds of live weight of the animal.

It seems logical to believe then that either brewers' dried grains or wheat distillers' grains may be used as all or any part of the grain allowance for farm horses.

A REVISION OF THE NORTH AMERICAN SPECIES OF THE PHASIA COMPLEX (DIPTERA, TACHINIDAE)¹

BY A. R. BROOKS²

Science Service, Ottawa, Ont.

[Received for publication March 8, 1945]

SUMMARY

This paper is a revision of the North American species belonging to the *Phasia* complex as they occur north of Mexico. Twenty-three species and one subspecies belonging to ten genera are described and illustrated. Of these, one genus and eight species are recognized as new. A number of exotic genera are included in the keys for the purpose of comparison with our native forms.

Coquillett (1) placed the species belonging to the *Phasia* complex in two genera, *Phorantha* Rondani and *Alophora* R-Desvoidy, including some fifteen species, most of which he described at that time. Feeling that this revision was inaccurate as regards its commonest species, Robertson (7) attempted to revise the concept of *Phorantha occidentis* (Wlk.) of Coquillett which in the revision was placed with seven synonyms; the opinion was expressed that the true *occidentis* was not identifiable and that *occidentis* of Coquillett contained at least three distinct species, two of which Robertson then described. More recently, Townsend (8) recognized nine distinct genera as applying to the North American members of the group, classifying the complex as part of the subtribe Phasiina. Townsend's classification on the whole has not been accepted by the North American workers, Curran (2) placing the species in two genera, *Ilyalomya* R-Desvoidy and *Alophora* R-Desvoidy, these two corresponding closely to Coquillett's *Phorantha* and *Alophora*.

HOST RELATIONS

The members of the *Phasia* complex possess in the females a long, sharp, piercing ovipositor with which thin shelled, unincubated eggs are injected directly into the body of the host. Known hosts are adult Hemiptera. Although adults of most species are rather common and easily captured around flowers, very little is known about their life histories or immature stages. Milliken and Wadley (5) working with *Ilyalomyiopsis aldrichi* Townsend (reported as *Phasia occidentis* Wlk.) a parasite of *Nysius ericae* Schill. in Kansas, gives a summary account of its life history: the life cycle requires about 25 days and in this respect bears a close relationship to the habits of the host; the parasitism is almost entirely confined to the females of *Nysius*, the destruction of the males being negligible; it was also

¹ Contribution No. 2362, Division of Entomology, Science Service, Department of Agriculture, Ottawa.

² Junior Entomologist.

found that although the host is not always destroyed the egg laying capacity is much reduced. Painter (6) reported that the parasitism of *Lygus pratensis* Say by *Alophorella aeneoventris robertsonii* Townsend (reported as *Alophora opaca* Coq.) to be 2 to 4% in the overwintering generation, the parasite laying its eggs in the fall and overwintering as a partially grown maggot in the host, pupating in the soil the following spring.

CLASSIFICATION AND CHARACTERS OF IMPORTANCE

The tribe Phasiini in the general conception (Townsend, 8) contains two well marked reproductive-habit groups, those genera as *Pallasia* R-D. (*Cistogaster* Lat.), *Xysta* Meig., *Ectophasia* Townsend and allies which lay flattened unincubated eggs externally on the host and the members of the *Phasia* complex which inject eggs into the host. These habits are closely correlated with the structures of the male and female reproductive organs, and while other body characters of the two groups appear to intergrade and overlap, the genitalic characters will separate the two.

The *Phasia* complex may be characterized as follows:

Body short and broad; abdomen oval and flattened, particularly in the male; chaetotaxy very poorly developed, the abdomen without macrochaetae or these very poorly developed; wings broad or narrow, generally with some darker markings but often clear; apical cell closed and with a long straight petiole; female genitalia in the form of a sharp piercer; male genitalia box-like, the large rectangular forceps covering most of the other structures.

Coquillett's division of the complex into two genera (1) was based on the bristling of the head, those species with the sides of the front hairy outside the frontal bristles being placed in the genus *Alophora* R-Desvoidy, while those without additional rows of hair on the front were placed in *Phoranthia*. This arrangement will successfully place our species in two groups, but other characters show that the grouping is largely artificial. Curran's division of the complex into two genera (2), based on the pleural hair, those with dense yellow hair being placed in *Alophora* R-Desvoidy, those with black pleural hair in *Hyalomya* R-Desvoidy, is even less illuminating as some species have both yellow and black hair on the pleura, and there is every gradation between the two extremes.

It becomes evident after an examination of the genera involved that these fall into a number of natural divisions, each division with its own range of variables and taxonomic characters, the characters employed in one division being only partly usable in the next. There is furthermore a great difference in the ease of separation of the genera in the different divisions. In other words we have stable or mature divisions and unstable or young divisions. What is not generally realized, however, is that this very difference in stability provides one of the best characters for separating the divisions. It is proposed in this paper to divide the North American representatives of the *Phasia* complex into five major divisions; division I,

Heyneophasia TT. and allies; division II, *Phasia* Latr. and allies; division III, *Paraphoranthia* TT. and allies; division IV, *Alophorella* TT. and allies; division V, *Hyalomya* R-D. and allies.

Of highest importance to our classification within the complex appears to be the structure of the head plus that of the wing venation. These characters outline in a general way the five main divisions. Characters of second importance appear to be the arrangement of bristles particularly on the head, plus the structure of the female abdomen in the *Phasia* and *Hyalomya* divisions where these characters are distinctive or the structure of the male wing in the *Alophorella* and *Hyalomya* divisions where the females are much alike. Of third importance (chiefly generic) are minor characters of the above plus colour and pollinosity.

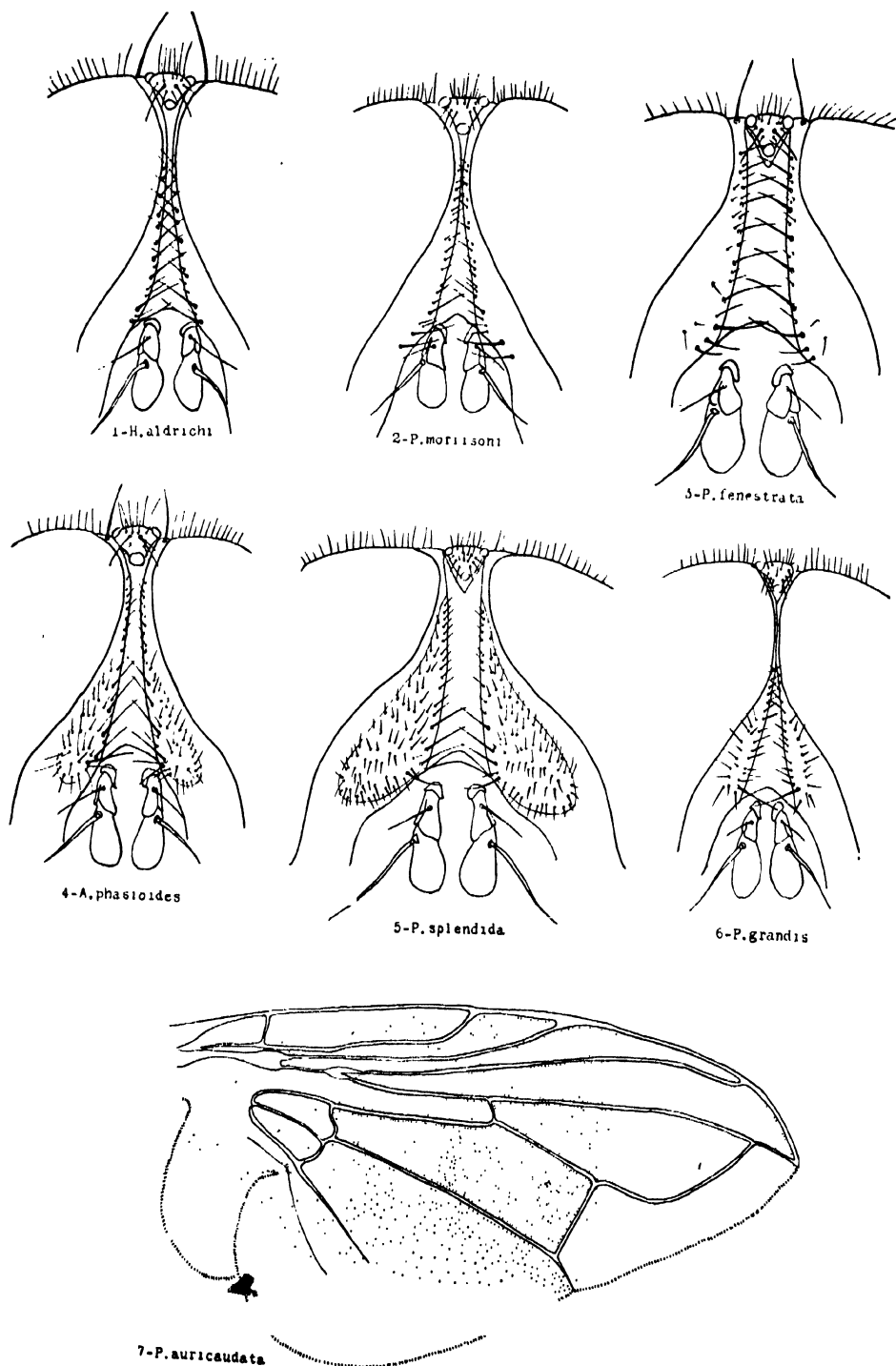
Colour characters of generic importance are found particularly in the male wing, the wings being whitish or not whitish, with markings which follow the wing veins, with markings which are confined to streaks without regard to the veins, or with the wing uniformly brownish or entirely clear. Characters of the pollinosity are found chiefly on the abdomen, the abdomen being covered with thick opaque pollen, with thin pollen, pollinose with shining spots, subshining or polished. It has been found that colour and pollinosity characters are some of the most reliable guides to the taxonomy of the whole complex.

Colour within a species appears to have a very different value to colour within a genus. In the species *Alophorellopsis purpurascens* TT., *Alophorella aeneoventris* Will. or in *Alophoropsis* species for example, the smaller specimens have a much poorer developed wing pattern in proportion to the total size than do the larger specimens, and in forms with broadened male wings, the ratio of the wing width to the wing length diminishes as the specimens become smaller. Thus in one species it is possible to have small specimens with clear, narrow wings along with large specimens with broad pictured wings.

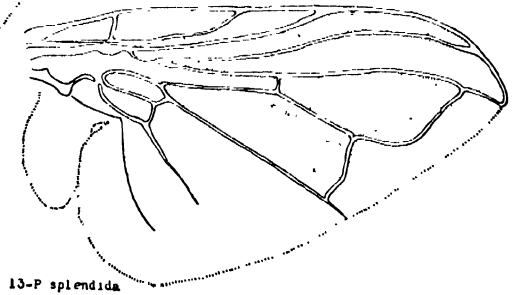
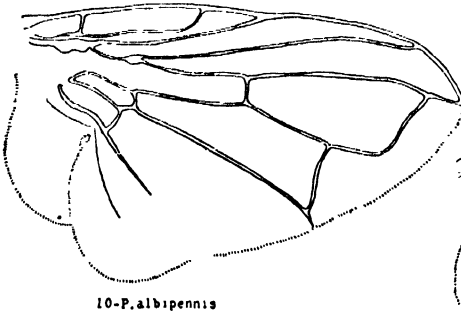
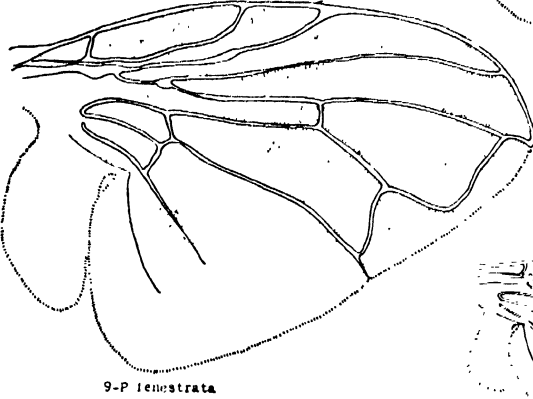
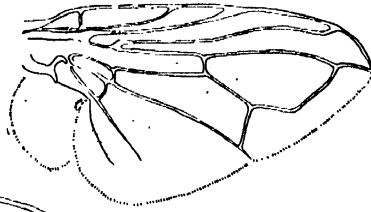
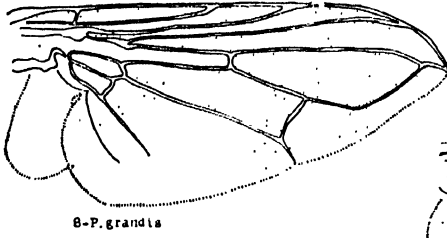
One of the great difficulties encountered, particularly in the *Alophorella* division will be the determination of the females. This sex lacks the characteristic wing shapes and wing patterns found in the males, and the pollinosity of the abdomen tends to conform to one type. For this reason it should be made clear that the separation of the genera of the *Alophorella* division (the genera *Alophoropsis*, *Oedematopteryx*, *Euphorantha* and *Alophorella*) has been based on male characters not possessed by the female.

ACKNOWLEDGMENTS

The writer wishes to express thanks to the following persons for supplying him with specimens and information: to Professor N. Banks of the Museum of Comparative Zoology; to Drs. C. F. W. Muesebeck and M. T. James of the United States National Museum; to Dr. H. H. Ross of the Illinois State Museum; and H. J. Reinhard to whom a special debt is owed for providing many notes and information concerning types.



FIGURES 1-6. Male heads, dorsal view. Drawn to approximately the same size regardless of scale. 7. Male wing.



FIGURES 8-28. Male wings. Figures 7-24 are drawn to the same scale while Figures 25-28 are somewhat enlarged

KEY TO THE NORTH AMERICAN GENERA

1. Vertex over one-third head width in both sexes, the front equibroad; epistoma very short, about half as long as the clypeus; front without additional rows of hairs outside the frontal row but with three or four small, proclinate, orbital-like hairs, Tropical.....*Heyneophasia* Townsend
Vertex less than a fourth as wide as the head; epistoma as long as the clypeus.... 2
2. Two strong sternopleural bristles; epistoma perpendicular, not warped forward; parafrontals contiguous in both sexes (fig. 6); petiole of apical cell short, less than one-fifth as long as the preceding section of R_s , the cubitus very obtuse.....*Paraphoranthia* Townsend
Less than two sternopleurals or the epistoma strongly warped forward..... 3
3. Eyes separated by a distance greater than the width of the ocellar triangle (figs. 3, 5); frontalia very broad, at most slightly narrowed posteriorly; head very wide and flat; male wings generally whitish, pictured with brown; petiole of the apical cell generally less than one-fourth the length of the preceding section of R_s 4
Eyes separated by a distance less than the width of the ocellar triangle, the frontalia well narrowed posteriorly; head more rounded, not flattened across the top; petiole of the apical cell one-fourth to one-half the length of the preceding section of R_s ... 6
4. No sternopleural bristle; pleura and notum very heavily yellow haired; epistoma nearly perpendicular, only slightly warped forward; parafrontals with many rows of hairs outside the frontal row anteriorly; petiole of the apical cell about one-seventh as long as the preceding section of R_s , the apical crossvein joining R_s at an acute angle; piercer curved upwards, the sheath not flanged (*Alophora* R-Desvoidy), Europe.....*Phasia* Latreille
One sternopleural bristle; epistoma strongly warped forward; petiole of the apical cell about one-fourth the length of the preceding section of R_s ; piercer sheath flanged or curved downwards..... 5
5. Many additional rows of hairs present outside the frontal row anteriorly; wings only slightly widened in the male; male abdomen highly polished; piercer pointing downwards.....*Phasiomyia* Townsend
No additional rows of hair outside the frontal row; male wings generally very broad and the abdomen pollinose; piercer pointing upwards.....*Paraphasia* Townsend
6. One or more rows of hairs outside the frontal row anteriorly (fig. 4); petiole of the apical cell one-fourth to three-eighths the length of the preceding section of R_s ... 7
No hair strip outside the frontal row anteriorly (figs. 1, 2); petiole of the apical cell three-eighths to one-half as long as the preceding section of R_s 10
7. Male wings broad, the anal area enlarged and the costa strongly bulging or arcuate; fifth vein rarely reaching the wing margin; wings generally whitish, strongly marked with brown along the veins..... 8
Male wings narrow, the anal area not particularly enlarged, the costa straight or slightly arcuate; fifth vein reaching the wing margin; wings not whitish, hyaline with brown stains which do not follow the wing veins..... 9
8. Male abdomen heavily pollinose, the pollen dense, opaque, yellowish-grey.....*Oedematopteryx* Townsend
Male abdomen shining or subshining, the pollen thin, greyish or bluish grey.....*Alophoropsis* Townsend
9. Abdomen brownish or greyish pollinose; vibrissae not well differentiated from the accessory vibrissae; wings nearly uniformly darkened; length 6-12 mm.....*Euphorantha* Townsend
Abdomen shining or subshining, at least in the central region; vibrissae well differentiated; wings generally conspicuously stained with brown across the centre; length 3-6 mm.....*Alophorella* Townsend

10. Male wings broadened, at least in the anal area; colour whitish hyaline, marked with brown basally or along the veins; abdomen nearly round to elliptical, shining or thinly pollinose with distinct shining spots at the bases of the hairs or evenly pollinose..... 11
 Male wings narrow; colour clear..... 12
11. Abdomen highly polished, at least centrally; cheeks one-third eye height; third vein bristled at the base; species 8-9 mm. long, Europe..... *Phorantha* Rondani
 Abdomen more or less pollinose, usually punctate; cheeks one-sixth eye height; third vein with at most one small bristle at the base; species 2-6 mm. long..... *Alophorellopsis* Townsend
12. Presutural supraalar bristle absent; ocellar and vertical bristles absent or hair like; frontal bristles extending two or three below the anterior points of the frontalia; wings long, narrow and pointed; legs stout, the hind tibia of the male short, three-fourths to four-fifths as long as the femora, curved; piercer long, hooked up at the tip, the sheath flanged; third sternite of the female obsolete.... *Phoranthella* Townsend
 Presutural supraalar present; ocellar and vertical bristles present, strong or weak; frontal bristles stopping at the anterior points of the frontalia or one below..... 13
13. Seventh sternite of the female (piercer sheath) flanged, pointing downwards, the piercer pointing upwards; cheeks linear, mostly facing downwards (*Parallophora*, Girschner), Europe..... *Hyalomya* R-Desvoidy
 Seventh sternite of female not flanged, closely appressed to the piercer which points upwards; cheeks at least distinct when viewed in profile..... *Hyalomyiopsis* n. gen.

DIVISION I—*Heyneophasia* and allies

The genus *Heyneophasia* Townsend (genotype *H. heynei* Townsend, Costa Rica) has not been recovered from North America, north of Mexico, but in the tropical and subtropical regions from Mexico to Northern Argentina the various species appear to form a large part of the *Phasia* complex. From the descriptions it appears evident that Van der Wulp's *Hyalomyia munda*, *villosa*, *hebes*, *ochriceps* and *argenticeps* (9) belong either in *Heyneophasia* or a closely allied genus. Townsend also records *Hyalomyia ecitonis* Townsend (1897) as being referable to *Heyneophasia*.

Front very broad, one-third to one-half head width in both sexes, the front and face equibroad; parafrontals without additional rows of hairs outside the frontal row, but with three or four short, proclinate hairs in a row; ocellars and verticals developed; epistoma about half as long as the clypeus, warped in the clypeal plane, extending but little below the vibrissae. Claws and pulvilli about half to three-fourths as long as the last tarsal segment. Wings narrow; petiole of the apical cell one-third as long as the preceding section of R_5 ; R_5 with one or two bristles at the base; wings clear. Abdomen round, mostly shining with transverse pollinose bands in the male, thinly pollinose in the female, quite hairy. Piercer curved up; sheath broad and stout, somewhat knobbed at the tip, slightly turned down.

DIVISION II—*Phasia* and allies

This division contains some of the largest and most striking of our Phasine flies. On account of their large size, coloured wings and the tendency to develop thick, yellow pleural hair, these forms are largely those which have been determined as *Alophora* spp. by American workers in recent years.

The genus *Phasia* Lat. (*Alophora* R-Desvoidy) in its restricted sense has not been recovered from North America. While Coquillett used the name *Alophora* in a very broad sense, his character (hairy front) excluded members of the genus *Paraphasia* TT. which have no additional rows of hairs on the front. Coquillett's member of that genus was placed in his genus *Phoranthia* (as *nigrens* V. d. Wlp.).

In North America two well characterized genera are found, *Paraphasia* TT. and *Phasiomyia* TT., both genera being easily separated from each other and from the European *Phasia* by many definite characters. This relative ease of separation is in sharp contrast to that found in the *Alophorella* division in which the genera are poorly defined and highly variable.

Genus *Phasiomyia* Townsend

1915—*Phasiomyia* Townsend, Proc. Biol. Soc. Wash., XXVIII, 20; one species as *Alophora splendida* Coquillett (1902); Townsend, Manual of Myiology, VII, 67, 1938.

Length 6-8 mm. Black, the male abdomen highly polished; wings whitish, patterned with brown. Male head wide, flattened on top and the parafacials scooped out, the female front less flattened and the parafacials only slightly concave; eyes separated by a distance greater than the width of the ocellar triangle in the male (fig. 5), somewhat closer together in the female; frontalia wider than the parafrontals, equibroad; epistoma strongly warped forward, longer than the clypeus; parafacials wider than

the facialia, the two together equal to the width between the vibrissae; cheeks one-fourth to one-third eye height; ocellar and vertical bristles not differentiated; parafrontals with four to six additional rows of hairs outside the frontal row anteriorly, the hairs on a definite raised area; vibrissae weak; palpi long and enlarged apically. Acrostichals 0.1 (0.2); dorso-centrals 0.1 (1.2); intraalars 0.1; supraalars 1.1; lateral scutellars 2; sternopleurals 1. Wings narrow or slightly broadened, the costa straight or arcuate, the anal area enlarged; petiole of the apical cell just over one-fourth the length of the preceding section of R_5 ; 5R broad; cubitus a rounded right angle; M_1 joining R_5 nearly at right angles. Legs robust; femora of male enlarged; hind tibia curved. Abdomen broad, flattened and pointed; sternites all well formed; piercer moderately wide, curved ventrally, extending beyond the sheath; sheath very broad, shovel-shaped, also curved ventrally.

Superficially the females of this genus resemble the females of *Alophorella* and allies to a marked degree while the males are typical of the *Phasia* division. The structure of the ovipositor, however, is very different from *Alophorella*. Townsend compared *Phasiomyia* to *Alophoropsis* but the relationship appears to be a distant one.

Only one species is known.

***Phasiomyia splendida* (Coquillett)**

Alophora splendida Coquillett, Proc. U.S. Natl. Mus., XXV, 105, 1902, new name for *Alophora fenestrata* Bigot of Coquillett (1897) not of Bigot, 1889; type male, New Hampshire (U.S.N.M.).

Male. Antennae black; frontalia black; front dark grey, the pollen having a yellowish tinge; clypeus, epistoma, parafacials and cheeks slate grey, the cheeks yellow haired; palpi yellow.

Thorax dark; pleura, humeri, lateral line, prescutellar band and scutellum grey pollinose, the disc of the mesoscutum with a large patch of bright golden pollen, the rest of the mesonotum subshining black; pleural hairs yellow. Wings whitish hyaline or nearly clear, strongly or faintly marked with brown along the veins, the anal area and the posterior border whitish or clear (fig. 13); squamae brown, the lower half of the front scale whitish. Front femora with dense black hair dorsally, yellow hair ventrally; posterior femora with long, dense, black hair dorsally; claws and pulvilli very long.

Abdomen highly polished, purple to reddish, golden pollinose laterally and apically on the fourth segment, lightly greyish pollinose on the first segment; abdominal hair long, moderately dense, black on the dorsum, yellow on the venter.

Female. Generally smaller than the male; epistoma less projecting, the front narrower and the parafacials and cheeks narrower than in the male. Mesonotum dull black, the disc of the mesoscutum with a patch of brownish pollen; pleura mostly black haired. Wings narrow, clear, not marked with brown; veins yellow; squamae dark yellow. Legs black; femora not enlarged and without the characteristic hair patches of the male, wholly sparsely black haired. Abdomen subshining black, uniformly covered with greyish-yellow or brownish pollen which is evident when the abdomen is viewed from behind, the pollen thinner on the posterior edges of the segments and along the median line.

Distribution. ALBERTA (Slave Lake, Aug. 15-25): MAINE (Chamberlain Lake, Sept. 7; Mt. Katahdin, Aug.): NEW BRUNSWICK (Douglas, Aug. 7; Fredericton, Aug. 3): NEW HAMPSHIRE (Franconia, Sept.; White Mts.; Mt. Manodrock, Dec. 23; Base Mt. Wash., Aug. 21-Sept. 21; Kinsman Notch; Noxon Camp): NEW YORK (Oliverea, Sept. 3; Ithaca): NORTH CAROLINA (Mt. Mitchel, Aug. 22-Sept. 6): ONTARIO (Frater, Aug. 28; Algonquin Park; Lake Nipigon, July 23-28; Lake Abitibi, Aug. 15): PENNSYLVANIA (North Mt., Sept. 2): QUEBEC (Duchesnay, July 27; Bordeau, July 27; Awantjish, Aug. 4; Val. d'Espoir, Aug. 24-29; Cascapedia River, Sept. 6; Gaspe, Aug. 13): TENNESSEE (Smoky Mts., Sept. 1): VERMONT (Grand Isle, July 3; Peru, July 31): WASHINGTON (Seattle).

Genus **Paraphasia** Townsend

1915—*Paraphasia* Townsend, Proc. Biol. Soc. Wash., XXVIII, 20; one species as *Alophora fenestrata* Bigot (1889); Townsend, Manual of Myiology VII, 63, 1938.

Length 6-10 mm. Black; abdomen rounded, thinly pollinose; male wings generally broad, whitish, marked with brown. Head much wider than high, the front flattened and the parafacials scooped out; epistoma very long and strongly warped; eyes separated by a distance nearly equal to twice the width of the ocellar triangle in the male, slightly less in the female (fig. 3); frontalia about three times as wide as the parafrontals and nearly parallel-sided; parafacials much wider than the facialia, the two together narrower than the distance between the vibrissae; cheeks two-fifths eye height; ocellar and inner vertical bristles differentiated; no additional rows of hairs outside the frontal row anteriorly; vibrissae weak; palpi long and enlarged apically. Acrostichals 0.0; dorsocentrals 1.1; intraalars 0.1; supraalars 1.1; lateral scutellars 2; sternopleurals 1. Wings narrow to very broad, generally with an enlarged anal area and bulging costa in the male; petiole of the apical cell one-sixth to one-fourth the length of the preceding section of R_5 ; cubitulus generally a rounded right angle; M_1 joining R_5 at a right angle or nearly so. Abdomen broad and flattened; piercer heavy, short, slightly curved up; piercer sheath heavy, blunt, curved ventrally at right angles to the piercer.

The North American species may be separated as follows:

1. Legs entirely black. 2
 Legs at least partly reddish; male wings whitish, pictured with brown. *fenestrata* (Bigot)
2. Abdomen black with distinct bands of grey pollen; wings not whitish but transparent, the costal cell and the basal cells coloured with brown, leaving the apical third of the wing entirely clear; cubitulus at a marked obtuse angle. *nigra* n. sp.
 Abdomen mostly reddish, without distinct bands of pollen; male wing strongly whitish, the costal cell slightly brownish; cubitulus nearly a right angle. . . . *albipennis* n. sp.



***Paraphasia fenestrata* (Bigot)**

Alophora fenestrata Bigot, Ann. Soc. Ent. Fr., VIII, 255, 1889; type male, Nevada (Newmarket ?).

Phoranthia bidwelli Hine, Ohio Naturalist, II, 229, 1902; type male, Kansas (Ohio State U.); Townsend, Ins. Ins. Mens., IV, 128, 1916, synonymy.

Alophora magnapennis Johnson, Psyche, XI, 19, 1904; type, male, Montreal, Quebec (M. C. Z.): NEW SYNONYMY.

Phasia phasiatrata Smith, Psyche, XXII, 98, 1915; type, female, New Hampshire (U.S.N.M.); Townsend, Ins. Ins. Mens., IV, 128, 1916, synonymy.

Male. Length 8-10 mm. Antennae black, the second segment brownish, the third segment small and rounded, the second segment four-fifths as long as the third; arista thickened one-fourth way; frontalia dark reddish; front yellowish; clypeus, parafacials and cheeks grey; occiput grey with white hairs; palpi yellow.

Thorax dark; pleura, humeri, lateral line and the apical three-fourths of the scutellum greyish pollinose; mesonotum heavily golden-yellow pollinose with four darker vittae, the central pair found in front of the suture; pleural hair white, yellow or black. Wings very broad across the base (fig. 9), the costa strongly bulging and the anal area enlarged; colour whitish, strongly marked with brown in the costal region and along the veins, and with a distinct white mark extending from the costa to the centre of the discal cell; discal cell broad; cubitus at right angles, the apical cross vein joining R_5 at right angles; squamae wholly dark yellow or whitish in the central region. Legs reddish-yellow, the tarsi darker; femora not particularly enlarged, the hind tibiae slightly curved; femora clothed posteriorly with yellow hair, dorsally with black hair.

Abdomen nearly round, wider than the thorax and flattened, the genital segment clearly visible from above; colour wholly red or mostly black with a narrow reddish margin; dorsal abdominal hair short, thin and black, closely appressed; lateral and ventral hair long, dense, erect and yellow.

Female. Eyes separated by a distance equal to one and a half times the width of the ocellar triangle, the frontalia widening in front. Abdomen black, wholly brownish-yellow pollinose, the pollen thinner on the posterior fourth of segments one to three. Wings narrow, entirely clear. Otherwise except for sexual differences as in the male.

Distribution. DISTRICT OF COLUMBIA (Rock Creek, April 28-May 1): KANSAS (Lawrence): NEW YORK (Ithaca, May; Caroline, May 6): NORTH CAROLINA (Raleigh, April 2): ONTARIO (Ottawa, May 24; Constance Bay, May): PENNSYLVANIA (North Mt., June 7): QUEBEC (Hull, May; Aylmer, April 20; Laniel, May 24; Rigaud, May 29; St. Hilaire, May 21): VIRGINIA (Vienna, April 7; U. of Richmond, May 1): WASHINGTON (Seattle, April 8).

***Paraphasia albipennis* n. sp.**

Male. Length 10 mm. Antennae black, the second segment reddish; lunule shining black; the rest of the head, including the frontalia, heavily greyish pollinose; cheek and occiput white haired; vertex one-sixth head width; frontalia as broad as the ocellar triangle, slightly widened anteriorly; clypeus moderately and evenly concave; epistoma just projecting beyond the antennal prominence.

Thorax dark; pleura, lateral line and the apical half of the scutellum greyish pollinose; mesonotum and the basal half of the scutellum golden pollinose, the mesonotum showing four broad vittae, the central pair present before the suture; pleural hair white and yellow. Wings slightly widened at the base, the costa arcuate but not strongly bulging (fig. 10); colour entirely whitish, yellow at the base and with a dark brown spot at

the tip of the subcosta; cubitus at a slight obtuse angle, the apical cross-vein entering R_5 nearly at right angles; squamae white with a yellow border. Legs wholly black, the femora with long white hair posteriorly.

Abdomen mostly reddish, with the incisures and a broad median vitta black; lightly grey pollinose on the first segment and on the lateral edges of the following segments and in the central region; abdominal hairs fine, black on the dorsum, yellow on the venter.

Holotype. ♂, Saskatoon, Sask., 2.V.1940 (A. R. Brooks): No. 5588 in the Canadian National Collection, Ottawa.

***Paraphasia nigra* n. sp.**

Male. Length 8 mm. Antennae black, the second segment reddish; frontalia black; front greyish pollinose with a faint golden tinge; clypeus, parafacials, cheeks and occiput silvery grey pollinose; cheeks and occiput white haired; vertex one-sixth head width; epistoma evenly warped, the oral margin axis just longer than the antennal axis.

Thorax dark; pleura, humeri, lateral line and scutellum greyish pollinose; mesonotum golden-yellow pollinose with four distinct vittae, the central pair short; pleural hairs yellow or white. Wings narrow, slightly enlarged on the anal area, the costa straight, not bulging or arcuate (fig. 11); colour transparent, slightly whitish in the cells, marked with brown on the basal two-thirds, the brownish colour rather faint except in the costal cell; petiole of the apical cell two-sevenths as long as the length of the preceding section of R_5 ; cubitus broadly obtuse; M_1 joining R_5 at an acute angle; squamae dark brown, the lower half of the front scale white. Legs dark brown to black, uniformly coloured, the front and mid femora white haired posteriorly.

Abdomen wholly black, grey pollinose, the pollen covering the abdomen except on the narrow posterior edges of the segments which are shining black; abdominal hair black, each hair with a small shining spot at its base.

Female. Head as in the male but the front slightly narrower and the epistoma not so protuberant. Thorax black, lightly covered with greyish pollen; mesonotum greyish pollinose with four darker vittae. Wings narrow, entirely clear; squamae white, the anterior scale somewhat yellowish. Abdomen black with grey pollen on the anterior three-fourths of segment two, three and covering segment four except for the extreme tip; segment one, the posterior fourth of segments two and three and a faint central vitta shining black. Otherwise except for sexual differences as in the male.

Holotype. ♂, Ukian, California, 31.3.30 (C. C. Wilson); in the United States National Museum, Washington.

Allotype. ♀, Los Angeles Co., California, April (Coquillett), labelled "*Phorantha nigrens* Wlp." and "*Phorantha ? occidentalis* Wlk. typical"; in Washington.

Paratype. ♂, Knight's Lndg., California, 2.IV.32; in H. J. Reinhard's collection, College Station, Texas.

DIVISION III—*Paraphorantha* and allies

Members of this division are largely tropical or subtropical, only three species of *Paraphorantha* being recorded from United States.

Genus *Paraphorantha* Townsend

1915—*Paraphorantha* Townsend, Proc. Biol. Soc. Wash., XXVIII, 20; one species as *Alophora grandis* Coquillett (1897): Townsend, Manual of Myiology VII, 64, 1938.

Length 6-12 mm. Black, thinly greyish or yellowish pollinose; wings narrow. Head rotund; eyes large, nearly touching or very narrowly separated in both sexes (fig. 6); epistoma not warped forward, nearly vertical; frontal bristles weak and short, the parafrontals with an additional row of hairs outside the frontal row anteriorly; ocellar and vertical bristles absent; parafacials one and a half times as wide as the facialia, the two together as wide as the distance between the vibrissae; cheek one-sixth eye height. Acrostichals 0.1 (0.2); dorsocentrals 0.1 (1.1 or 1.2) intraalars 0.0 (0.1); supraalars 1.1; sternopleurals 2; lateral scutellars 2. Wings narrow in both sexes, pointed; petiole of 5R one-eighth to one-sixth as long as the preceding section of R_5 ; cubitulus very obtuse, the apical crossvein entering R_5 at an acute angle. Abdomen oval, evenly rounded, subshining with thin whitish or yellowish pollen. Legs normal, the tibiae and femora straight; claws and pulvilli very long in the male. Piercer narrow, curved upwards; piercer sheath long, two and a half times as long as the preceding sternite, curved upwards hiding the piercer.

The three North American species may be separated as follows:

1. Species 6-7 mm. long; abdomen black, distinctly yellowish-grey pollinose in the female, the male with broad brown bands on each segment or nearly uniformly brownish black; pleural hair black or yellowish..... *pollinosa* n. sp.
Species 9-12 mm. long; abdominal pollen not conspicuous in the female, the male with only one brown band at the most..... 2
2. Pleural hair white or yellowish; posterior two segments of the abdomen thinly golden pollinose in contrast to the greyish pollinose anterior segments; mesonotum rather distinctly vittate..... *auricaudata* n. sp.
Pleural hair black; abdomen subshining black, thinly whitish pollinose, the male with a brown band on segment two..... *grandis* (Coquillett)

Paraphorantha grandis (Coquillett)

Alophora grandis Coquillett, Rev. Tach., 45, 1897; type female, Lufkin. Texas (U.S.N.M.).

Male. Length 9-10 mm. Antennae black, the second segment reddish; arista long, tapered from base to apex; frontalia reddish, pinched out in front of the ocelli; parafrontals greyish with a faint yellowish tinge; parafacials and cheeks golden yellow; epistoma denuded; occiput grey with white hairs; palpi enlarged apically, dark yellow, strongly haired.

Thorax dark, subshining on the disc; humeri, lateral line and the apical half of the scutellum more noticeably grey; a pair of short, narrow, brownish vittae on the prescutum; basal half of the scutellum and a narrow band on the mesonotum just posterior to the suture dark brown; post-scutellum and pleura grey pollinose; pleural hair black. Wings narrow and pointed; colour uniformly brownish to nearly clear (fig. 8); squamae brown, the lower half of the top scale white. Legs black or dark brown.

the tip of the subcosta; cubitus at a slight obtuse angle, the apical cross-vein entering R_5 nearly at right angles; squamae white with a yellow border. Legs wholly black, the femora with long white hair posteriorly.

Abdomen mostly reddish, with the incisures and a broad median vitta black; lightly grey pollinose on the first segment and on the lateral edges of the following segments and in the central region; abdominal hairs fine, black on the dorsum, yellow on the venter.

Holotype. ♂, Saskatoon, Sask., 2.V.1940 (A. R. Brooks): No. 5588 in the Canadian National Collection, Ottawa.

***Paraphasia nigra* n. sp.**

Male. Length 8 mm. Antennae black, the second segment reddish; frontalia black; front greyish pollinose with a faint golden tinge; clypeus, parafacials, cheeks and occiput silvery grey pollinose; cheeks and occiput white haired; vertex one-sixth head width; epistoma evenly warped, the oral margin axis just longer than the antennal axis.

Thorax dark; pleura, humeri, lateral line and scutellum greyish pollinose; mesonotum golden-yellow pollinose with four distinct vittae, the central pair short; pleural hairs yellow or white. Wings narrow, slightly enlarged on the anal area, the costa straight, not bulging or arcuate (fig. 11); colour transparent, slightly whitish in the cells, marked with brown on the basal two-thirds, the brownish colour rather faint except in the costal cell; petiole of the apical cell two-sevenths as long as the length of the preceding section of R_5 ; cubitus broadly obtuse; M_1 joining R_5 at an acute angle; squamae dark brown, the lower half of the front scale white. Legs dark brown to black, uniformly coloured, the front and mid femora white haired posteriorly.

Abdomen wholly black, grey pollinose, the pollen covering the abdomen except on the narrow posterior edges of the segments which are shining black; abdominal hair black, each hair with a small shining spot at its base.

Female. Head as in the male but the front slightly narrower and the epistoma not so protuberant. Thorax black, lightly covered with greyish pollen; mesonotum greyish pollinose with four darker vittae. Wings narrow, entirely clear; squamae white, the anterior scale somewhat yellowish. Abdomen black with grey pollen on the anterior three-fourths of segment two, three and covering segment four except for the extreme tip; segment one, the posterior fourth of segments two and three and a faint central vitta shining black. Otherwise except for sexual differences as in the male.

Holotype. ♂, Ukiah, California, 31.3.30 (C. C. Wilson); in the United States National Museum, Washington.

Allotype. ♀, Los Angeles Co., California, April (Coquillett), labelled "*Phoranthia nigrens* Wlp." and "*Phoranthia ? occidentalis* Wlk. typical"; in Washington.

Paratype. ♂, Knight's Lndg., California, 2.IV.32; in H. J. Reinhard's collection, College Station, Texas.

DIVISION III—*Paraphorantha* and allies

Members of this division are largely tropical or subtropical, only three species of *Paraphorantha* being recorded from United States.

Genus *Paraphorantha* Townsend

1915—*Paraphorantha* Townsend, Proc. Biol. Soc. Wash., XXVIII, 20; one species as *Alophora grandis* Coquillett (1897): Townsend, Manual of Myiology VII, 64, 1938.

Length 6-12 mm. Black, thinly greyish or yellowish pollinose; wings narrow. Head rotund; eyes large, nearly touching or very narrowly separated in both sexes (fig. 6); epistoma not warped forward, nearly vertical; frontal bristles weak and short, the parafrontals with an additional row of hairs outside the frontal row anteriorly; ocellar and vertical bristles absent; parafacials one and a half times as wide as the facialia, the two together as wide as the distance between the vibrissae; cheek one-sixth eye height. Acrostichals 0.1 (0.2); dorsocentrals 0.1 (1.1 or 1.2) intraalars 0.0 (0.1); supraalars 1.1; sternopleurals 2; lateral scutellars 2. Wings narrow in both sexes, pointed; petiole of 5R one-eighth to one-sixth as long as the preceding section of R_5 ; cubitulus very obtuse, the apical crossvein entering R_5 at an acute angle. Abdomen oval, evenly rounded, subshining with thin whitish or yellowish pollen. Legs normal, the tibiae and femora straight; claws and pulvilli very long in the male. Piercer narrow, curved upwards; piercer sheath long, two and a half times as long as the preceding sternite, curved upwards hiding the piercer.

The three North American species may be separated as follows:

1. Species 6-7 mm. long; abdomen black, distinctly yellowish-grey pollinose in the female, the male with broad brown bands on each segment or nearly uniformly brownish black; pleural hair black or yellowish..... *pollinosa* n. sp.
Species 9-12 mm. long; abdominal pollen not conspicuous in the female, the male with only one brown band at the most..... 2
2. Pleural hair white or yellowish; posterior two segments of the abdomen thinly golden pollinose in contrast to the greyish pollinose anterior segments; mesonotum rather distinctly vittate..... *auricaudata* n. sp.
Pleural hair black; abdomen subshining black, thinly whitish pollinose, the male with a brown band on segment two..... *grandis* (Coquillett)

Paraphorantha grandis (Coquillett)

Alophora grandis Coquillett, Rev. Tach., 45, 1897; type female, Lufkin. Texas (U.S.N.M.).

Male. Length 9-10 mm. Antennae black, the second segment reddish; arista long, tapered from base to apex; frontalia reddish, pinched out in front of the ocelli; parafrontals greyish with a faint yellowish tinge; parafacials and cheeks golden yellow; epistoma denuded; occiput grey with white hairs; palpi enlarged apically, dark yellow, strongly haired.

Thorax dark, subshining on the disc; humeri, lateral line and the apical half of the scutellum more noticeably grey; a pair of short, narrow, brownish vittae on the prescutum; basal half of the scutellum and a narrow band on the mesonotum just posterior to the suture dark brown; post-scutellum and pleura grey pollinose; pleural hair black. Wings narrow and pointed; colour uniformly brownish to nearly clear (fig. 8); squamae brown, the lower half of the top scale white. Legs black or dark brown.

Abdomen subshining black, the greyish-white pollen thin; anterior half of the basal segment, a broad band on the anterior half of the second segment and a small median spot on segments three and four brown.

Female. Head similar to the male; mesonotum uniformly thinly grey pollinose. Wings clear; veins yellowish; squamae yellowish. Abdomen subshining black, very thinly coated with whitish pollen, the pollen more evident on the posterior half of the second segment, on the anterior edges of the segments and laterally.

Distribution. GEORGIA (Stone Mt., Nov. 17): ILLINOIS: MASSACHUSETTS (Melrose Hghds., Sept. 13; Forest Hills, Sept. 12): MISSISSIPPI (Agr. Coll., April 6): NORTH CAROLINA (Raleigh, late Oct.): TEXAS (College Station, Nov. 3; Willis; Lufkin): VIRGINIA (Great Falls, Oct. 8; Upton, July 2).

***Paraphoranthia pollinosa* n. sp.**

Male. Length 7 mm. Antennae black, the second segment reddish; frontalia black; parafrontals greyish with a faint yellowish tinge; parafacials and cheeks yellow; occiput grey with white hairs; palpi dark yellow.

Thorax black, lightly grey pollinose on the humeri, lateral line, pleura and on the apical half of the scutellum, thinly yellowish pollinose on the prescutum; vittae distinct when viewed from behind; pleural hair mostly yellow, occasionally black or partly black. Wings nearly clear, lightly brown fumose (fig. 12); veins brown; squamae dark brown, the anterior scale whitish on the lower half. Legs black.

Abdomen dark, subshining; anterior half of the first segment without pollen, the posterior half brownish; segments two, three and four brownish pollinose centrally, greyish laterally, the pollen very thin, only becoming evident when the abdomen is viewed from behind.

Female. Head similar to the male; frontalia dark reddish to black. Pleural hair mostly yellow with intermixed black hair above; mesonotum conspicuously greyish white pollinose, four broad, darker vittae being evident. Wings clear; squamae white. Abdomen dark, conspicuously yellowish-grey pollinose, the pollen somewhat thinner on the posterior fourth of the segments and along the median line.

Holotype. ♂, Chesapeake Beach, Md., 20.IX.14 (C. T. Greene); in the Museum of Comparative Zoology, Cambridge.

Allotype. ♀, same data as holotype.

Paratypes. 6 ♂, 5 ♀, Chesapeake Beach, Md., 21.IX.-, 18.IX.- (N. Banks) in Cambridge. 1 ♂, College Station, Texas, 5.21.19 (H. J. Reinhard), 1 ♀, College Station, Tex., April 21, 1939 (H. Menusan) "a parasite of *Chlorachroa ligata* Say," 1 ♀, Winter Haven, Tex., 5.21.1936 (S. E. Jones) in H. J. Reinhard's collection. 1 ♀, Anacostia, D. C., 24.9.14 (R. C. Shannon), 1 ♂, Bennings, D. C., 10.22.14 (R. C. Shannon), 1 ♀ Beltsville, Md., July 9, 1916 (W. L. McAtee), 1 ♂, 2 ♀, Chesapeake Beach, Md., 21.IX.-, 19.VII.20 (N. Banks, Bridwell), 1 ♀, Grove Hill, Md., 20.IX.16 (C. H. Townsend), 1 ♂, Santa Clara Co., Cal. (Baker) in the United States National Museum.

***Paraphoranthia auricaudata* n. sp.**

Male. Length 11 mm. Antennae black; frontalia brownish; front silvery-grey pollinose, the parafacials and cheeks golden; occiput dark grey with pale yellow hairs; palpi yellow.

Thorax black, the mesonotum with conspicuous grey pollen; four very broad non-pollinose vittae extending from the head to the scutellum, these vittae about four times as broad as the pollinose strips between them; scutellum grey pollinose, shining at the base; pleura grey pollinose, pleural hair yellow. Wings broad, the costa slightly arcuate but not bulging (fig. 7); petiole of the apical cell about one-fifth the length of the preceding section of R_5 ; basal two-thirds of the wing dark brown, the apical one-third hyaline except the extreme tip of R_5 which is brownish; veins brown, bordered with brownish-yellow rays; squamae brown, the lower half of the front scale lighter in colour. Legs black, the tibiae brownish; front femur with yellow hair posteriorly.

Abdomen broad and long, subshining; segments one and two thinly whitish-grey pollinose, the pollen more evident laterally and on the basal half of the first segment; posterior two segments thinly golden pollinose; abdominal hair black on the dorsum, yellow on the venter.

Female. Head similar to the male, the parafacials and cheeks greyish with a slight golden tinge; occipital ruff white. Thorax as in the male, the greyish pollen being somewhat denser and the vittae narrower; sternopleural hairs yellow, the mesopleural hairs black. Wings clear; veins brown; squamae white with a yellowish tinge. Abdomen rather strongly pollinose, especially posteriorly; anterior two abdominal segments thinly greyish pollinose, the posterior two golden pollinose.

Holotype. ♂, Milton, Oregon, June 22, 1938 (K. Gray and J. Schuh); in H. J. Reinhard's collection, College Station, Texas.

Allotype. ♀, Cuchara, Colorado, 8.7.1940 (F. Snyder).

Paratypes. 1 ♀, Yakima, Wash., Aug. 27, 1931 (A. R. Rolfe) in Reinhard's collection. 1 ♂, Mt. Moscow, Idaho, VI.24 (J. M. Aldrich) in the United States National Museum. 1 ♂, Springdale, Ark., Aug. 1933, 1 ♂, Colton, Cal., 10.13 (F. A. Eddy) in Cambridge.

DIVISION IV—*Alophorella* and allies

The four North American genera which belong in this division are particularly difficult to deal with. The genera have been founded on outstanding species which have certain weak morphological characters in chaetotaxy, body form and wing shape, but these species appear to represent only one end of the variation within the genus, species at the other end of the variation being much more difficult to place. The weak morphological characters are, however, strongly supported by colour characters, extent of pollinosity, general size and male wing form and it is in the *Alophorella* division that this type of character is particularly useful. The females appear to possess no characters of value to separate them either generically or specifically.

Genus *Alophoropsis* Townsend

1915—*Alophoropsis* Townsend, Proc. Biol. Soc. Wash., XXVIII, 20; one species as *Alophora phasioides* Coquillett (1897): Townsend, Manual of Myiology VII, 39, 1938.

Length 5-10 mm. Black with thinly pollinose or shining abdomen and broad whitish, usually pictured wings. Head quadrate, wider than high; flat front longer than the face; clypeus gently concave; epistoma as long as the clypeus, projecting, the oral margin axis slightly longer than the antennal axis; parafacials flat, one and one-half times as wide as the flattened facialia, the two together equalling three-fourths the distance between the vibrissae; eyes separated by a distance slightly less than the width of the ocellar triangle; frontalia distinct throughout, slightly widened anteriorly (fig. 4); vertical and ocellar bristles hair like, hardly distinguishable; parafrontals with two or three rows of hairs outside the frontal row anteriorly; frontal row extending well below the anterior points of the frontalia; facialia bristled on the lowest third; vibrissae strong and well differentiated; cheek one-fifth to one-sixth eye height. Acrostichals 0.1, very weak; dorsocentrals 0.1; intralars 0.1, very weak; supraalars 1.1; lateral scutellars 2; sternopleurals 1. Male wings very broad basally, the costa strongly bulging; petiole of 5R one-fourth to three-eighths the length of the preceding section of R_5 ; cubitulus rounded; M_1 joining R_5 at right angles; C_1 generally not reaching the margin of the wing. Legs stout but femora not particularly enlarged; claws and pulvilli of male very long. Abdomen broad and flattened in the male, less so in the female; abdominal hair short, semierect. Piercer narrow, slightly curved upwards; sheath shallow, also curved upwards, covering the piercer except at the tip.

The North American species may be separated as follows:

1. Wings whitish hyaline without brown markings; abdomen with a pronounced brassy tinge; length 6 mm..... *nitida* (Coquillett)
Wings pictured with brown or black..... 2
2. Abdomen greyish pollinose, the pollinosity at times quite thin; wings heavily patterned with brown or nearly clear..... *phasioides* (Coquillett)
Abdomen polished purple, at least in the central region..... 3
3. Anterior three-fourths of the wing very dark, the white marking in the cells very faint; wing markings black; length 7 mm..... *alaskensis* n. sp.
Anterior three-fourths of the wing with a definite pattern of white and brown, the central region of the cells strongly whitish; wing markings brownish; length 4-6 mm..... *occidentalis* n. sp.

Alophoropsis nitida (Coquillett)

Alophora nitida Coquillett, Rev. Tach., 45, 1897; type male, Virginia (U.S.N.M.).

I have not seen this species and so can only repeat the original description. It seems probable that this form and *phasioides* are the same, *phasioides* being quite variable with smaller specimens possessing nearly clear wings.

"Males; black, the palpi yellow, abdomen with a pronounced brassy tinge, shining, thinly white pollinose; thorax when viewed from behind thinly white pollinose except the front end and two subdorsal vittae behind the suture; eyes separated as widely as the posterior ocelli, calypteres

greyish white, wings whitish hyaline, base to tip of second basal cell yellow, costa strongly arcuate, last section of third vein nearly half as long as the preceding section; length 6 mm. Potomac Creek, Virginia. A single male specimen collected May 23, 1896 by C. W. Johnson."

***Alophoropsis phasioides* (Coquillett)**

Alophora phasioides Coquillett, Rev. Tach., 46, 1897; type male, Franconia, New Hampshire (U.S.N.M.).

Male. Length 6-10 mm. Antennae black, the second segment obscurely red tipped; head greyish pollinose, the front generally with a yellowish or golden tinge; cheeks and occiput white haired; palpi yellow.

Thorax black, thinly greyish pollinose; mesonotum with four darker vittae, the vittae narrow and well defined on the prescutum, very broad, short and only narrowly separated on the mesoscutum; pleural hair mostly black, humeral hair yellow. Wings very broad, the costa strongly bulging and the anal area enlarged (fig. 15); colour whitish, strongly marked along the veins with broad brown bands, the area just beyond the tip of R_1 extending from the costa to the middle of the discal cell having a tendency to be whitish, the brown vein markings in this area narrower, sometimes entirely lacking; veins yellow; squamae yellowish, the lower half of the front scale white. Legs black, the front and hind femora with yellow hair posteriorly.

Abdomen black, subshining, uniformly covered with thin greyish pollen or at times a somewhat darker median vitta present; abdominal hairs semierect, short and black dorsally, long, erect and yellow laterally and ventrally.

Small specimens of the species tend to have the brown colouring of the wing more diffuse and fainter than the larger specimens.

Distribution. MASSACHUSETTS (Melrose Hghds., June 11; Holliston, July 14); NEW HAMPSHIRE (Franconia); NEW YORK (Dix Hills, L.I., June 15); ONTARIO (Ottawa, July 14); QUEBEC (Aylmer, Oct. 5; Abbotsford, Sept. 20; Rigaud, Oct. 11).

***Alophoropsis alaskensis* n. sp.**

Male. Length 7 mm. Antennae and arista wholly black; frontalia black; head entirely greyish pollinose, the anterior half of the front somewhat darker; cheeks and occiput with white hair; palpi yellow or brown.

Thorax black, black haired, thinly greyish pollinose; mesonotum with four broad darker vittae, these narrower and separated in front of the suture but coalescing behind. Wings very broad, the costa strongly bulging and the anal area enlarged (fig. 14); colour whitish, strongly marked with black along the veins, yellowish at the base, the centre of cells 5R and 1M a little lighter in colour, the anal area without dark markings; veins black; squamae translucent, the upper scale whitish on its lower half. Legs black, the femora with black and yellow hair posteriorly.

Abdomen dark, mostly shining purple in the central region; the segments laterally, the posterior third of the third segment and the whole of the fourth and fifth segments with greyish pollen, the pollen very thin except at the margin of the abdomen; abdominal hairs semierect, long and black dorsally, yellowish ventrally.

Female. Wings narrow, entirely clear, yellowish at the base; veins mostly yellow; squamae white, a little yellowed laterally. Abdomen black; the first abdominal segment, a narrow median vitta on segments two and three and the extreme posterior margins of segments two and three without pollen, the rest of the abdomen thinly greyish pollinose, the pollen somewhat browner centrally; abdominal hair black, moderately long. Otherwise except for sexual characters similar to the male.

Holotype. ♂, Matanusta, Alaska, 27.8.1943; in the United States National Museum, Washington.

Allotype. ♀, same data as type.

Paratypes. 1 ♂, 3 ♀, same data as type.

***Alophoropsis occidentalis* n. sp.**

Male. Length 5-6 mm. Antennae black, the second segment somewhat reddish apically; frontalia black to reddish; front, face, cheek and occiput greyish pollinose, the pollen without a yellowish shade.

Thorax dark, thinly greyish pollinose; mesonotum with four darker vittae, the vittae narrow and separated on the prescutum except in front, very broad and confluent on the mesoscutum; pleura black haired. Wings very broad, the anal area enlarged and the costa bulging (fig. 16); colour whitish, strongly marked with brown along the veins, the centres of 5R and 1M whitish; squamae white, the posterior scale with a faint brown mark centrally. Legs black, the femora with white hair posteriorly.

Abdomen mostly shining purple, thinly greyish pollinose around the margin and at the apex; at times the pollinosity is quite extensive covering all but a small area of the abdomen centrally; abdominal hairs long, semi-erect, black dorsally, yellowish-white laterally and ventrally.

Holotype. ♂, White Mts., New Mexico, NFk Ruidoso, about 8200 ft., on flowers of *Solidago trinervata*, 8-17 (Townsend); in the United States National Museum, Washington.

Paratypes. 1 ♂, same data as type, 1 ♂, Vernon, B.C., 20.IX.1918 (M. K. Ruhmann) in Washington. 1 ♂, Waterton, Alta., July 11, 1923 (H. L. Seamans), 1 ♂, Lethbridge, Alta., July 10, 1922 (H. L. Seamans) in the Canadian National Collection, Ottawa. There are also several broken specimens in the Canadian National Collection from the type locality, Slave Lake, Alta., Aug. 14, 1924; Mozart, Sask., Sept. 12, 1937; Brant, Alta., Aug. 5, 1929 and Bozeman, Mont., Sept. 8, 1916.

Genus *Oedematopteryx* Townsend

1916—*Oedematopteryx* Townsend, Proc. U.S. Natl. Mus., XLIX, 633; two species, including *Alophora pulverea* Coquillett (1897), genotype by original designation; Townsend, Manual of Myiology VII, 60, 1938.

Length 5-7 mm. Narrowed, abdomen heavily yellowish-grey pollinose; wings broadened in the male. Head one-third wider than high; flat front longer than the face; clypeus gently concave; epistoma as long as the clypeus, projecting, the oral margin axis slightly longer than the antennal axis; parafacials not scooped out, twice as wide as the flattened facialia, the two together three-fourths as wide as the distance between the vibrissae;

eyes separated by a distance slightly less than the width of the ocellar triangle; frontalia distinct, widened anteriorly; vertical and ocellar bristles hair like; parafrontals with two or three rows of hairs outside the frontal row anteriorly; facialia bristled on the lowest third to half; vibrissae well differentiated from the accessory vibrissae; cheek one-fifth to one-sixth eye height. Acrostichals 0.1; dorsocentrals 0.1 (1.1), the presutural when present very fine; intraalars 0.1, very weak; supraalars 1.1; lateral scutellars 2; sternopleurals 1. Male wings very broad, enlarged in the anal region, the costa bulging; petiole of 5R one-fourth the length of the preceding section of R_5 ; cubitulus a rounded right angle; M_1 joining R_5 nearly at right angles; C_1 rarely reaching the margin of the wing. Legs stout but the femora not particularly enlarged. Abdomen rather narrow, flattened in the male, very heavily and uniformly covered with yellowish-grey pollen; abdominal hairs moderately long, semierect.

The three North American species may be separated as follows:

1. Wings strongly whitish, marked with brown..... 2
Wings clear or only slightly whitish, the brown colouring diffuse over the whole membrane although more concentrated along the veins and anteriorly; front with a strong yellowish or golden tinge to nearly grey..... *fumosa* (Coquillett)
2. Brown colouring along the veins very weak, usually confined to the anterior veins; front shining grey; squamae white, Western..... *opaca* (Coquillett)
Wings strongly marked with brown especially in the costal region; front usually with a golden or yellowish cast; squamae partly yellowish, Eastern.... *pulverea* (Coquillett)

Oedematopteryx pulverea (Coquillett)

Alophora pulverea Coquillett, Rev. Tach., 46, 1897; type male, Ontario (U.S.N.M.).

Male. Length 6-7 mm. Antennae black or the second segment reddish; frontalia black; front grey, usually with a very strong golden or yellowish tinge, rarely silvery grey; face, cheeks and occiput silvery grey; palpi yellow.

Thorax dark, lightly grey pollinose; mesonotum showing four darker vittae, the vittae joined together anteriorly, separated posteriorly, the darker markings of the prescutum bordered with greyish pollen next the suture; on the mesoscutum the vittae are very broad, not separated, the central pair short; humeri and the anterior part of the mesopleura with yellow hair, a few hairs on the sternopleura also yellow. Wings very broad, the costa excessively bulging (fig. 19); colour strongly whitish with broad brown markings along the veins, this brown marking being very distinct in the costal and subcostal cells, along R_2 , R_3 and R_5 and at the apex; veins yellow (this wing pattern is very variable, some specimens having nearly clear wings with only faint brown markings, other specimens having the brown bands bordering all the veins); squamae white with a yellow tinge centrally and on the upper scale. Legs black, femora with yellow or white hair behind.

Abdomen covered with heavy, opaque, yellowish-grey pollen with traces of a narrow vitta on segment one; abdominal hairs black on the dorsum, long, erect and yellow laterally and ventrally.

Distribution. CONNECTICUT (Colebrook, July 11); ILLINOIS: INDIANA (LaFayette, June 1-Oct. 19); MARYLAND (Grove Hill, Oct. 30; College Park, Oct. 30); MASSACHUSETTS (Amherst, June 18; Melrose Hghds.,

June 18-Aug. 18; Jaunton, Sept.; Agawam, Oct. 27; North Saugus, July 2); NEW BRUNSWICK (Barber, June 23-Aug. 3; Fredericton, Aug. 2); NEW HAMPSHIRE (Base Mt. Wash., Sept. 3; Kinsman Notch, July 7); NEW JERSEY (Del. W. Gap, July 12); ONTARIO (Lake Abitibi, July 19-Aug. 12; Brockville, Oct.; Simcoe, June 3); PENNSYLVANIA (Hazelton, Sept. 28); QUEBEC (Montreal, Oct. 13; Hull, Sept. 25; Aylmer, Sept. 28-Oct. 5; Knowlton, Aug. 6; Ladysmith, Aug. 6; Clarenceville, July 16); VIRGINIA (Falls Church, Sept. 20); WISCONSIN Milwaukee, Oct. 1).

***Oedematopteryx opaca* (Coquillett)**

Alophora opaca Coquillett, Rev. Tach., 44, 1897; type male, Eastern Washington (U.S.N.M.).

Male. Length 5-6 mm. Antennae black; front, face, cheeks and occiput wholly silvery grey pollinose. Thorax dark, coloured as in *pulverea*. Wings broad, the costa bulging (fig. 17); colour whitish, faintly brown in the costal cell and at the apex; squamae white, slightly yellowish on the border. Legs black, the femora with white or yellow hair posteriorly. Abdomen uniformly and heavily yellowish-grey pollinose, the anterior half of the first segment and a narrow vitta on the first segment dark.

Distribution. ALBERTA (Waterton, July 14); BRITISH COLUMBIA (Vernon, Sept. 9; Trinity Valley, July 27); WASHINGTON.

***Oedematopteryx fumosa* (Coquillett)**

Alophora fumosa Coquillett, Rev. Tach., 46, 1897; type male, New Jersey (U.S.N.M.).

Oedematopteryx fumosa (Coq.), Townsend, Proc. U. S. Natl. Mus., XLIX, 633, 1916.

Male. Length 4.5-6 mm. Antennae black; front greyish to strongly golden pollinose; face, cheeks and occiput grey. Thorax dark, coloured as in *pulverea*. Wings broad, the costa bulging but not strongly so (fig. 18); colour clear or very slightly whitish posteriorly, the brown colouring diffused over the whole membrane, making the wings comparatively dark, the costal region and veins more heavily bordered with brown; squamae white, brownish or yellow in the central region. Legs black, the femora with yellow or white hair posteriorly. Abdomen uniformly yellowish-grey pollinose with evidence of a dark vitta on segment one.

Distribution. ILLINOIS (Douglas, May 11); NEW MEXICO (White Mts., Aug. 17); NEW YORK (Wilmington Notch, July 1; Geneva, ex *Lygus caryae*); ONTARIO (Ottawa, Aug. 14; Simcoe, May 29-July 3; Orillia, June 10; Jordan, July 8); VIRGINIA (Potomac Creek, May 23; Falls Church, May 3-June 18).

Genus *Euphorantha* Townsend

1915—*Euphorantha* Townsend, Proc. Biol. Soc. Wash., XXVIII, 20; one species as *Alophora diversa* Coquillett (1897); Townsend, Manual of Myiology VII, 52, 1938.

Length 6-12 mm. Rather narrow; abdomen thinly pollinose; wings narrow, not whitish. Head one-third wider than high; flat front longer than the short face; epistoma long and warped, the antennal and oral margin axes equal; parafacials not scooped out, slightly wider than the flat facialia; the two together four-fifths as wide as the distance between the vibrissae; eyes narrowly separated by a distance slightly less than the

width of the ocellar triangle in the male, very narrowly separated in the female; frontalia distinct throughout although very narrowly so in the female; vertical and ocellar bristles present but fine; two or three rows of hairs outside the frontal row anteriorly; frontal bristles and hair strips extending well below the anterior points of the frontalia; vibrissae strong but not well differentiated from the accessory vibrissae; facialia bristled one-third to one-half way. Acrostichals 0.1; dorsocentrals 1.1 (1.2), the anterior fine; intraalars 0.1; supraalars 1.1; lateral scutellars 2; sternopleurals 1, occasionally 2; pleural hair black. Wings not widened, not whitish or having the veins margined with brown; petiole of 5R one-fourth to one-fifth as long as the preceding section of R_5 ; cubitulus broadly rounded; M_1 joining R_5 at a slight acute angle; C_1 reaching the margin of the wing. Legs normal, femora not particularly enlarged. Abdomen about as wide as the thorax, wholly pollinose; sternites all well formed; piercer moderately broad, curved dorsally; sheath shallow and broad, about as long as the preceding sternite, slightly curved dorsally.

The two North American species may be separated as follows:

Length 9-12 mm. Abdomen uniformly greyish-brown or greyish pollinose, somewhat darker on the median line and on the posterior edges of the segments; piercer sheath very heavy, boat shaped with a blunt tip.....*diversa* (Coquillett)

Length 6-7 mm. Abdomen greyish-white pollinose, the posterior third to half of the intermediate segments brownish, the banded effect being quite conspicuous in the male; piercer sheath narrow, very shallow, the tip pointed.....*subopaca* (Coquillett)

***Euphorantha diversa* (Coquillett)**

Alophora diversa Coquillett, Rev. Tach., 45, 1897; type female, Massachusetts (U.S.N.M.).

Male. Length 10-12 mm. Antennae and arista black; frontalia black; palpi yellow; parafrontals heavily golden pollinose, the facialia golden next the vibrissae; face, cheeks and occiput silvery-grey, the cheeks with white hair.

Thorax dark, thinly grey pollinose; mesonotum with four broad, darker vittae, the vittae narrower and distinct on the prescutum, very broad and only narrowly separated on the anterior half of the mesoscutum; pleural hair black. Wings not whitish, hyaline, heavily coloured with brown especially on the anterior half and in the central region (fig. 20); squamae dark brown, the upper scale whitish on its lower half. Legs black; femora with some short white hair posteriorly.

Abdomen black, mostly opaquely greyish or yellowish-grey pollinose, the fourth segment generally more yellowish than the intermediate segments; first segment shining; a very narrow median vitta and the posterior edges of the intermediate segments subshining; abdominal hairs semierect, black on the dorsum and laterally, yellowish ventrally.

Female. Length 9-10 mm. Front silvery-grey or yellowish-grey pollinose. Wings entirely clear; veins yellow; squamae pale yellow. Abdomen black, the posterior segments heavily grey pollinose; first segment, a narrow median vitta and the posterior margin of segment two subshining. Piercer sheath particularly stout, boat shaped with a blunt tip. Otherwise as in the male.

Distribution. DISTRICT OF COLUMBIA (Washington, Oct. 14; Georgetown, Oct.); GEORGIA (Stone Mt., Nov. 17); ILLINOIS (Alto Pass, May 5; Makanda, Oct. 6); INDIANA (LaFayette, Oct. 9); MARYLAND (Grove Hill, Oct. 30; Glen Echo, Oct. 22); MASSACHUSETTS (Beverly, Oct. 11; Reading, Sept. 30); MISSISSIPPI (Agr. Col., April); NEW YORK (Oswego, Oct. 4); OHIO (Cincinnati, Sept. 25); ONTARIO (Jordan, Sept. 20; Apple Hill, Oct. 4); PENNSYLVANIA (Hazelton, Sept. 20); QUEBEC (Aylmer, Sept. 28; Hull, Aug. 26; Abbotsford, Sept. 20); TEXAS (College Station, Oct. 29); VIRGINIA (4-mile Run, Oct. 11; Great Falls, Oct. 23).

***Euphorantha subopaca* (Coquillett)**

Alophora subopaca Coquillett, Rev. Tach., 47, 1897; type male, Woodbury, N.J. (U.S.N.M.)
Euphorantha subopaca (Coq.), Townsend, Manual of Myiology VII, 53, 1938.

Male. Length 5-7 mm. Antennae and arista black; front heavily golden or yellowish pollinose; face, cheeks and occiput grey.

Mesonotum mostly subshining black, the grey pollen very thin; vittae as in *diversa* but very ill-defined; pleural hair black. Wing not whitish, almost uniformly brown, sometimes with the central region darker (fig. 21); squamae dark brown. Legs black, the femora with black hair.

Abdomen black, mostly greyish-white pollinose; first segment, a narrow median vitta and the posterior edges of the intermediate segments without pollen; intermediate segments with a broad band of brownish pollen on the posterior half of each segment; abdominal hairs erect, fine, wholly black.

Female. The females average slightly smaller than the males; front greyish or yellowish-grey pollinose; wings entirely clear, veins yellow; squamae white or yellowed in the central region. Abdomen mostly greyish-white pollinose, the first segment and a narrow median vitta without pollen; posterior third of intermediate segments each with a brown pollinose band; piercer sheath very narrow and shallow, with a pointed tip; otherwise as in the male.

Distribution. DISTRICT OF COLUMBIA (Tennallytown, Oct. 27); ILLINOIS (White Heath, May 9; Douglas, May 9; Savannah, June 14); INDIANA (Elkhart; LaFayette, Oct. 19); MAINE (Bar Harbour, Aug. 2); MARYLAND (Chesapeake Beach, Sept. 17-25; Lakeland, Sept. 6; Grove Hill, Oct. 30; New Bedford); MASSACHUSETTS (Milton; Waquoit, Sept. 21; Wellesley, Oct. 1; Holliston, Oct. 6); NEW BRUNSWICK (Douglas, Aug. 17); NEW JERSEY (Riverton, Oct. 12-20; Westville, May 19); NEW YORK (Ithaca, July 31); ONTARIO (Ottawa, June 10; Jordan, July 11); PENNSYLVANIA (Manayunk; Montg. Co., July 4); QUEBEC (Aylmer, Oct. 5; Norway Bay, Aug. 24); SOUTH CAROLINA (Clemson, Oct. 11); VIRGINIA (Mt. Vernon, Sept. 20; Roselyn, May 1; 4-mile Run, Oct. 11; Potomac Creek, May 23); WISCONSIN (Milwaukee; Chicago, May 8-Sept. 7).

Genus *Alophorella* Townsend

1912—*Alophorella* Townsend, Proc. Ent. Soc. Wash., XIV, 45; one species as *Thereva obesa* Fabricius (1798); Townsend, Manual of Myiology VII, 36, 1938.

European systematists have had considerable difficulty in coming to an agreement on the identity of *obesa* Fab. Girschner (3) divided the

species into four varieties—*obesa* Fab. (as *obesa umbripennis* Girschn.), *nervosa* Meig. (as *obesa nebulosa* Girschn.), *nebulosa* Panz. (as *obesa fascipennis* Girschn.) and *violacea* Meig. (as *obesa latipennis* Girschn.). The variation attributed to these so-called varieties corresponds closely to the diversity shown by the three genera *Euphorantha*, *Alophoropsis* and *Alophorella* of this paper.

It is evident also from Townsend's descriptions of *Alophorella* (9) that he had no very definite picture of *obesa* when the genus was erected; in his keys *Alophorella* is described with "male wings normal" while in the text "wings short and broad, normally in the male with anal angle much enlarged and costa bulging on the prestigma." Because of the variation in European determinations of *obesa* and the inconsistencies in Townsend's generic descriptions a somewhat arbitrary stand has been taken in applying the concept of *Alophorella* to *Ilyalomys aeneoventris* and allies which includes the European variety *obesa nebulosa* Panz.

For the purpose of this summary the following limit is placed on the genus:

Length 3-6 mm. Black, the abdomen shining or subshining brownish or purplish at least in the central region; wings narrow or slightly widened, not whitish, clear or stained with brown, the staining not following the veins. Head one-third wider than high; flat front longer than the face; epistoma long and warped forward, the antennal and oral margin axes about equal; parafacials not scooped out, the facialia plus the parafacialia about three-fourths as wide as the distance between the vibrissae; eyes narrowly separated, the frontalia distinct throughout; vertical and ocellar bristles distinct although fine; front with two or three rows of hairs outside the frontal row anteriorly; vibrissae strong, generally distinct and larger than the accessory vibrissae. Thoracic chaetotaxy as in *Euphorantha*. Wings usually not widened, but in some specimens with an arcuate costa and slightly enlarged anal area; colour clear or brown stained; petiole of 5R about one-third the length of the preceding section of R₅; C₁ reaching the margin of the wing. Abdomen oval, shining brownish or purplish in the central region or with very light brownish pollen in this region. Piercer narrow, curved up; sheath narrow, long triangular, about twice as long as the preceding sternite.

In North America two species of *Alophorella* occur. Both of these are highly variable, containing specimens in which the male wings are either wide or narrow, stained or clear.

Male abdomen highly polished purple, at least centrally; squamae white; front silvery grey.....*polita* n. sp.

Male abdomen thinly greyish or brownish pollinose, subshining centrally; squamae generally brownish or with a yellow tinge; front golden, brownish or yellowish-grey.....*aeneoventris* (Williston)

***Alophorella polita* n. sp.**

Male. Length 4-6 mm. Antennae and arista black, the second antennal segment somewhat reddish; frontalia velvety black; front, face, cheeks and occiput greyish pollinose, the front somewhat darker in colour; cheeks and occiput white haired; palpi long, yellow.

Thorax dark, thinly greyish pollinose; mesonotum with four darker vittae, the vittae on the prescutum narrow and separated except in front, very broad and only narrowly separated on the mesoscutum, the central pair short; scutellum subshining; pleural hair black. Wing narrow, the costa slightly arcuate and the anal area somewhat enlarged (fig. 24); colour clear with a brownish stain in the costal cells and extending in a triangular-shaped stain from the tip of R_1 to the posterior cross vein; squamae white. Legs black, the femora with some white hair posteriorly.

Abdomen mostly shining purple, thinly greyish pollinose around the margin and over the apex; abdominal hair semierect, black on the dorsum, yellow on the venter.

Female. Head and thorax coloured as in the male. Wing narrow, wholly clear without brown markings; veins yellow; squamae white. Abdomen black, thinly pollinose over the posterior three segments, the pollen of segments two and three very thin, subshining brownish centrally, greyish laterally; segment four greyish pollinose, the pollen thinner centrally. Otherwise except for sexual differences as in the male.

Holotype. ♂, White Mts., New Mexico, NFk Ruidoso, about 8200 ft. on flower of *Solidago trinervata*, 8.17 (Townsend): in the United States National Museum, Washington.

Allotype. ♀, same data as type.

Paratypes. 5 ♂, 3 ♀, same data as type, 3 ♀, White Mts., New Mexico, 8.20 (Townsend), 1 ♀, White Mts., New Mexico, 8.3 (Townsend), 1 ♂, 1 ♀, Moscow, Idaho (Aldrich), 1 ♂, Lewiston, Idaho (Aldrich), 1 ♀, Minot, N.D., June 18, 1918 (J. M. Aldrich), 1 ♂, Colorado Springs, Colo., July (Townsend), 2 ♂, University of Colorado, Boulder, Colo., Oct. 2, 1917 and Oct. 1, 1919, 1 ♂, Edmonton, Alta., 27.VII.1925 (O. Bryant) in the U.S.N.M., Washington. 1 ♂, 1 ♀, Tahique, New Mexico, 25.VI.41 (E. L. Todd), 1 ♂, 1 ♀, Boulder, Colo., 3.VI.1932 (M. T. James) in Reinhard's collection, College Station, Texas. 1 ♂, Gallatin Co., Mont., July 28, 1913 (H. E. Smith) in the M.C.Z., Cambridge. 1 ♂, Seton Lake, Lillooet, B.C., 4.VI.1926 (J. McDunnough), 1 ♂, Vernon, B.C., Aug. 12, 1917 (M. H. Ruhmann), 1 ♀, Slave Lake, Alta., Aug. 15, 1924 (Bryant), 1 ♂, Mont. Exp. Stat., Bozeman, Montana, July 1, 1916; 1 ♀ Gallatin Co., Montana, Aug. 1, 1917, 1 ♂, Lethbridge, Alta., June 18, 1926 (H. L. Seamans) in the Canadian National Collection, Ottawa.

Alophorella aeneoventris (Williston)

Hyalomyia aeneoventris Williston, Trans. Ent. Soc. Amer., XIII, 286, 1886; type male, Washington (Kansas?).

Hyalomyia robertsoni Townsend, Proc. Ent. Soc. Wash., II, 136, 1891; type female, Illinois (Kansas); Robertson, Can. Ent., XXXIII, 285, 1901, synonymy.

Phasia brevineura West, Jour. N.Y. Ent. Soc., XXXIII, 123, 1925; type male, Ithaca, New York (Cornell): NEW SYNONYMY.

Phasia furva West, Jour. N.Y. Ent. Soc., XXXIII, 123, 1925; type female, Truro, Nova Scotia (Cornell): NEW SYNONYMY.

This well known species occurs over most of the continent in two rather poorly characterized geographical subspecies or races.

Alophorella aeneoventris aeneoventris (Williston).

Male. Length 6-7 mm. Antennae and arista black; frontalia black; parafrontals dark grey pollinose, sometimes slightly yellowish; face, cheeks and occiput silvery grey, the cheeks with white hairs; palpi yellow.

Thorax dark, lightly grey pollinose; mesonotum with four darker vittae which are narrower and more widely separated on the prescutum but very wide, confluent or very narrowly separated behind the suture, the central pair short; scutellum brownish, grey at the sides. Wings broadened, the anal area somewhat enlarged and the costa arcuate (fig. 22); colour clear, strongly marked with brown in the costal region and centrally, often with a very distinct central brown band; squamae white, brownish or yellowish in the central region. Legs black, the femora with some white hair posteriorly.

Abdomen subshining brownish, the pollen of the central region very thin, only evident when the specimen is viewed from behind, the lateral margins of segments two and three and the whole of segment four and five with conspicuous grey pollen; abdominal hair wholly black, semierect.

Female. Wings narrow, clear with yellow veins; squamae translucent. Abdomen black, greyish and brownish pollinose, the brownish pollen of the central regions of segments two and three and along the posterior margins of these segments very thin, only evident when the abdomen is viewed from behind; lateral margins of segments two and three and the whole of segment four covered with greyish pollen; otherwise except for sexual differences as in the male.

Distribution. ALBERTA (Evansburg, June 30); BRITISH COLUMBIA (Victoria, Oct. 10; Royal Oak, Sept. 13; Vernon, Sept. 10; Carson, Sept. 15); WASHINGTON (Spanaway, July 2).

Alophorella aeneoventris robertsonii (Townsend)—

This form is the commonest Phasiine in the Eastern part of the continent and probably the most variable.

Male. Length 3-6 mm. Antennae black, the second segment sometimes brownish or reddish apically; frontalia black; front greyish-yellow, brownish or golden pollen; face, cheeks and occiput silvery grey, the cheeks with white hair; palpi yellow.

Thorax as in *aeneoventris aeneoventris*, the greyish pollen somewhat more distinct than in that form. Wings narrow, the anal area not enlarged and the costa straight or very slightly arcuate (fig. 23); colour clear, the wings of the larger specimens stained with dark brown in the costal cells and with a brown streak across the centre, those of the smaller specimens nearly or quite clear, the brown stains obsolete; squamae generally dark brown or yellowish, the lower half of the front scale white. Legs black, the femora with some white hair posteriorly.

Abdomen black, the posterior three segments covered with very thin brownish and greyish pollen which is only evident when the specimen is viewed from behind, the pollen of the central region brownish, subshining, that on the lateral margins and at the apex bluish-grey.

Female. Front silvery-grey to yellowish-grey; legs wholly black haired; wings narrow, entirely clear; veins yellow; squamae white with a yellowish or darker area in the centre; abdomen mostly as in the male but the pollen heavier.

Distribution. ALBERTA (Lethbridge; Slave Lake, Aug. 15; Wabamun, July 2-5); BRITISH COLUMBIA (Trinity Valley, July 25); CALIFORNIA (Carmel, May 21); COLORADO (North Park, July); DISTRICT OF COLUMBIA: IDAHO (Moscow, July 31-Sept. 1); ILLINOIS (Urbana, Sept. 26; Odin, May 28; Pulaski, June 2; Monticello, June 28); INDIANA (LaFayette, May 1-Oct. 27; Shelby, May 24; S. Wanatch, June 1; Attica, Oct. 7); MANITOBA (Teulon, Sept. 22); MARYLAND (College Park, Oct. 30; Beltsville, July 7; Grove Hill, Oct. 30-Nov. 2; Chesapeake Beach, Sept. 9); MASSACHUSETTS (Melrose Hghds., July 7-Oct. 16; Holliston, June 1-July 17; Reading, Sept. 24; Tyngsboro, Sept. 25; Lexington, July; N. Andover, Sept. 25; Agawam, Oct. 10; N. Saugus, July 30; Wellesley, Aug. 15; Chicopee, July 8; Mt. Holyoke Gap, Sept. 17); NEW BRUNSWICK (Fredericton, July 10; McGivney, July 12); NEW HAMPSHIRE (Jackson, Sept. 25; Alstead, Aug. 5; White Mts.; Franconia, Aug. 6; Base Mt. Wash., Aug. 27-Sept. 1; Noxon Camp, July 5; Kinsman Notch, July 7); NEW JERSEY (Riverton, Sept. 20-Oct. 10; Clementon, June 8; Ramsay, May 16); NEW YORK (Ithaca, Aug. 25-Sept. 19; McLean Res., Aug. 24-Sept. 24; Atwater, July 16; Honoey's Falls, July 11-Aug. 18; Wilmington Notch, Aug. 1); NORTH CAROLINA (Black Mts., May); NOVA SCOTIA (Kings County, Aug. 10); ONTARIO (Ottawa, April 8-Oct. 18; Jordan, July 14-Sept. 20; Fitzroy, July 25; Simcoe, May 28-June 29; Gananoque, July 9; Lake Abitibi, July 3-25); PENNSYLVANIA (Clarks Val., June 28); QUEBEC (Aylmer, June 13-Sept. 28; Hull, Sept. 20; Laniel, July 24; Norway Bay, Aug. 25; Montreal, Sept. 8; Abbotsford, June 18-Sept. 6); VERMONT (Rutland, Aug. 1-15; Chittenden, Aug. 1-15); VIRGINIA (Potomac Creek, May 25; Falls Church, May 3-Sept. 20; Glencarlynn, May 20; Louisa, Oct. 16; Great Falls, Oct. 23; Chain Bridge, Oct. 3); WASHINGTON (Spanaway, June 30-July 3); WISCONSIN (Milwaukee, Aug.).

DIVISION V—*Hyalomya* and allies

This entire division plus members of the genus *Paraphasia* (DIVISION II) were placed in the genus *Phorantha* by Coquillett; all but one of the species were placed as synonyms of *occidentis* Wlk. This lumping has caused sad confusion in the subsequent determinations of the various species and in the host records attributed to *occidentis*.

The genus *Phorantha* Rondani (genotype *Conops subcoleoptrata* Linne) and the genus *Hyalomya* R-Desvoidy (genotype *Phasia pusilla* Meigen) in their restricted senses have not been recorded from North America.

Genus *Phoranthella* Townsend

1915—*Phoranthella* Townsend, Pr. Biol. Soc. Wash., XXVIII, 23; one species as *P. morrisoni* Townsend (1915); Townsend, Manual of Myiology VII, 68, 1938.

Length 4-5 mm. Robust, short with clear narrow wings and thinly pollinose abdomen. Head wider than high; nearly flat front longer than the concave face; epistoma long, well warped forward, the oral margin axis slightly longer than the antennal axis; eyes very narrowly separated,

the frontalia pinched out in front of the ocelli (fig. 2); parafacials slightly wider than the facialia, the two together being five-sixths as wide as the distance between the vibrissae; vibrissae strong, but not well differentiated from the accessory vibrissae; frontal bristles extending two or three below the lower point of the frontalia, in one row; vertical bristles absent or hardly differentiated; ocellar bristles weak or absent, somewhat stronger in the female; palpi as long as the antennae, enlarged apically; cheek one-sixth eye height.

Acrostichals 0.1; dorsocentrals 0.1 (1.1); intraalars 0.0; supraalars 0.1; lateral scutellars 2; sternopleurals 1 (rarely 2). Wings narrow, pointed, clear, longer than the abdomen (fig. 26); petiole of 5R half as long as the preceding section of R_5 ; cubitus broadly rounded; M_3 midway; squamae very broad. Legs stout, femora enlarged; claws and pulvilli very long in the male; hind tibia short and curved, three-fourths to four-fifths as long as the hind femur; bristles long and stout; hind femora with two or three very stout preapical spines antero-dorsally, these spines about as long as the width of the femur where situated; hind tibia with two or three long, stout anterodorsals and two posterodorsals; mid tibia with a stout anteroventral and a shorter anterodorsal and posterodorsal.

Abdomen short and pointed; abdominal hairs erect, moderately dense; female sternites strongly drawn together and humped, the third sternite obsolete, the sixth sternite very large; sheath broad, curved ventrally; piercer narrow with a hooked tip, curved dorsally.

Phoranthella morrisoni Townsend

? *Hyalomyia punctigera* Townsend, Proc. Ent. Soc. Wash., II, 135, 1891; type male, Dixie Landing, Va. (Kansas?).

Phoranthella morrisoni Townsend, Proc. Biol. Soc. Wash., XXVIII, 23, 1915; Manual of Myiology VII, 68, 1938; type female, Georgia (U.S.N.M.).

The type of *punctigera* could not be located but the description fits this species better than any other. *P. morrisoni* TT. was erected for a specimen determined by Coquillett as *Phoranthella occidentis* (Wlk.) but it remained undescribed until 1938.

Male. Antennae and arista black; frontalia black; front, face, cheeks and occiput silvery grey; cheeks white haired; palpi dark brown or black; two or three accessory vibrissae about as long as the vibrissae present.

Thorax dark; humeri, lateral line and pleura grey pollinose; mesonotum and scutellum shining or subshining black, the mesonotum sometimes faintly grey pollinose in front of the scutellum; pleural hairs black. Wings clear or fumose basally; veins yellow; squamae white, yellowish centrally. Legs wholly black; pulvilli grey.

Abdomen black, greyish pollinose centrally on the first segment, posteriorly on the second and on the whole of segments three, four and five; most of the first segment and a triangular spot on segments two to four dark; abdominal hairs dense, erect, black, each hair set in a shining non-pollinose black spot.

Female. Slightly smaller than the male; a row of five or six stout bristles on the oral margin next to the vibrissae present, each as stout as the vibrissae; mesonotum more distinctly pollinose than in the male with distinct vittae on the prescutum. Wings clear; squamae white; otherwise coloured as in the male.

Distribution. ARIZONA (Palmerlee, May); DISTRICT OF COLUMBIA (Eastern Branch, Oct. 22); IDAHO (Moscow, Sept. 1; Boise); ILLINOIS (DuBois, Aug. 9; Algonquin, Oct. 8; Mason City, June 5); INDIANA (LaFayette, Oct. 19); MARYLAND (Beltsville, May 28; Grove Hill, Nov. 2); MASSACHUSETTS (N. Andover, July 16; Melrose Hghds., July 14; Cohasset, Aug. 19); NEVADA (Ormsby Co., July 6); NEW JERSEY (Malagra, July 2); NEW MEXICO (Las Cruces, Aug. 31); TEXAS (College Station, May–Nov. 12; Austin, Oct. 7; Dallas, April 19, Neuscest, April 25); VIRGINIA (Mt. Vernon, Oct. 30; Potomac Creek, May 23).

Genus *Alophorellopsis* Townsend

1926—*Alophorellopsis* Townsend, Gen. Musc. Hum. Trop. Am. 209; one species as *A. capitata* Townsend (l.c., 284, 1926–Brazil); Manual of Myiology VII, 36, 1938.

The genotype *capitata* differs from the two North American species included in the genus in several respects, chief of which include the broad triangular wings in the female which are broadened as in the males of the other species; a very narrow front, the minimum width being less than the diameter of an ocellus; the presence of a small seta at the base of the third vein; a somewhat different arrangement of the scutellar bristles; the extensively pollinose abdomen.

The following generic description is taken from the two North American species which are tentatively referred here.

Length 2½–6 mm. Narrowed, black; male wings whitish, the anal area enlarged; abdomen generally lightly pollinose with shining spots. Head wider than high, more or less semicircular in profile; the flat front longer than the face; epistoma strongly warped forward; parafacials slightly wider than the facialia, the two together about as wide as the distance between the vibrissae; eyes separated by a distance equal to three-fourths the width of the ocellar triangle, the frontalia obsolete on the posterior half; ocellar and vertical bristles differentiated, often weak; frontal bristles stopping near the anterior points of the frontalia, in one row; vibrissae differentiated in the male but not in the female; palpi short, somewhat enlarged apically.

Acrostichals 0.1; dorsocentrals 1.1; intraalars 0.1; supraalars 1.1; lateral scutellars 2; sternopleurals 1. Wings enlarged in the anal area, the costa straight or arcuate; petiole of 5R nearly half as long as the preceding section of R₅; cubitus broadly rounded. Legs stout, the hind tibiae of the male somewhat shorter than the hind femora; claws and pulvilli of the male long.

Abdomen short and rounded to elliptical, black, generally lightly pollinose with distinct shining spots; piercer narrow, curved up; sheath closely appressed to the piercer, also curved up.

The two North American species may be separated as follows:

Male wings with strongly arcuate or bulging costa; abdomen wholly pollinose, without conspicuous shining spots..... *argentifrons* n. sp.
Male wings with straight costa, enlarged only in the anal area; abdomen shining or with conspicuous spots..... *purpurascens* (Townsend)

***Alophorellopsis argentifrons* n. sp.**

Male. Length 6 mm. Head wholly bright silvery pollinose; frontalia deep velvety black; arista ringed with brown above the swelling; palpi brown.

Thorax black, thinly greyish pollinose; prescutum with two narrow shining vittae in the acrostichal rows and a broader lateral vitta on each side. Legs shining black. Wings very broad across the base, the anal area enlarged and the costa arcuate (fig. 27); colour whitish, with all the veins except the anal broadly bordered with brown so that the whole anterior half of the wing appears coloured, the centres of the cells somewhat lighter; C_1 not reaching the posterior wing margin; squamae largely white, the lower lobe broadly bordered with brown.

Abdomen subshining brownish purple, broadly pollinose laterally on segments one and two with silvery pollen; segments three and four wholly yellowish-grey pollinose. Abdomen narrow and rather long.

Holotype. ♂, Oliver, B.C., 28.VI.1923 (C. B. Garrett): No. 5592 in the Canadian National Collection, Ottawa.

***Alophorellopsis purpurascens* (Townsend)**

Hyalomysia purpurascens Townsend, Proc. Ent. Soc. Wash., II, 137, 1891; type female, Illinois (U.S.N.M.).

Phorantha calyprata Coquillett, Rev. Tach., 44, 1897; type male D.C. (U.S.N.M.): NEW SYNONYMY.

Phorantha humeralis Robertson, Can. Ent., XXXIII, 286, 1901; type male, Carlinville, Illinois (Illinois). NEW SYNONYMY.

Male. Length 2.5 mm. Antennae black; front, face, cheeks and occiput silvery-grey; palpi dark brown.

Thorax dark, the mesonotum thinly brownish-grey pollinose; prescutum marked with a broad V or W-shaped marking formed from the coalescing of the central vittae; on the mesonotum the central vittae are very broad and joined, short, the lateral vittae continuous with the lateral vittae of the prescutum; pleural hair black. Wings distinctly whitish except in very small specimens which have nearly clear wings; anal area enlarged, costa straight (fig. 28); colour typically whitish with brown markings along the veins, these markings sometimes nearly as extensive as in *argentifrons*, but usually only the anterior basal region so marked, sometimes the wings practically without brown; squamae wholly deep velvety black or with a central white region. Legs black.

Abdomen mostly shining brownish-green to purplish, thinly greyish pollinose laterally and on the apical segments, each hair with a conspicuous shining spot at the base; at times however, the abdomen is wholly shining black without pollen while at others the black shining spots are reduced; abdominal hair long, erect and black.

Female. Head similar to the male. Thorax black, the mesonotum more distinctly grey pollinose than in the male, the vittae narrower. Wings moderately wide, whitish, without brown markings; squamae white, a little yellowed on the edges. Abdomen black, the posterior three segments and a central spot on segment one covered with shining grey pollen, each hair with a black basal spot which is somewhat smaller than those of the male.

Distribution. DISTRICT OF COLUMBIA (Eastern Branch, Sept. 22); GEORGIA (Peach Co., May 29, ex *Sehirus cinctus* P. deB.); IDAHO (Moscow, July 12–Aug. 21); ILLINOIS (Peoria, May 20, Algonquin, Aug. 16; Mason City; Urbana, June 18; Champaign, July 14; Anna, May 17); INDIANA (LaFayette, June 21–Oct. 23; Logansport, Aug.); MARYLAND (Plummers Is., June 7); MEXICO; MISSISSIPPI (Agr. Coll., May 5; Starkville, June 9); NEW MEXICO (Sororro, Rio Beneto, Las Cruces); NORTH CAROLINA (Raleigh, June 12); ONTARIO (Jordan, July 17; Fitzroy, July 25); QUEBEC (Lanquar, July 21); TENNESSEE (Nashville, Nov. 5); TEXAS (College Station, Sept. 11; Victor, Oct.); VIRGINIA (Falls Church, Sept. 17–Nov. 13); WASHINGTON (Spokane, June).

In this species small specimens tend to have a narrower, clearer wing and less pollinosity on the abdomen than do the larger specimens. In the series examined for this study, very small specimens with narrow, nearly clear wings and shining black abdomen were particularly common in the north west (Washington), medium sized specimens with narrow, whitish wings and slightly pollinose abdomen formed the major constituent of the species in the central states while the large specimens with broad, white and brown wings and more heavily pollinose abdomen were commoner in the East. Both the large and medium sized specimens were found throughout the range but only in the Washington series are there any very small, shining black forms. The intergradation, however, is very complete and no characters could be found that would suggest varieties or subspecies.

Genus *Hyalomylopsis* n. gen.

Genotype. *Hyalomyia aldrichi* Townsend, Proc. Ent. Soc. Wash., II, 136, 1891.

Length 2.5–6 mm. Black; wings narrow, hyaline; abdomen thickly covered with grey pollen. Head nearly round when viewed from in front, slightly wider than high; nearly flat frontal profile well sloped, one-half longer than the face; face concave; clypeus somewhat depressed, one and a half times as long as wide, parallel sided; epistoma as wide as the clypeus, half as long as same, well warped forward, the oral margin axis longer than the antennal axis; eye very large, the upper facets larger than the lower; cheek about one-eighth eye height; eye separated by a distance less than the width of the ocellar triangle, the frontalia generally obliterated on the posterior third; ocellar and inner vertical bristles developed in both sexes; frontal bristles stopping at the antennae base, the parafrontals bare outside the frontal row (fig. 1); parafacials one and a half times as wide as the frontalia, the two together three-fourths as wide as the distance between the vibrissae; vibrissae short but well differentiated; antennae reaching three-fourths of the way to the vibrissae; arista thickened one-half way; palpi slightly enlarged at the tip.

Thorax narrower than the head; acrostichals 0.1; dorsocentrals 1.1; intraalars 0.1; supraalars 1.1; sternopleurals 1; pteropleural as long as the sternopleural; lateral scutellars 2, the hind decussate. Wings narrow, clear, the costa straight and the anal area not enlarged (fig. 25); petiole of the apical cell nearly half as long as the preceding section of R_5 ; M_3 midway between R_5 and the broadly rounded cubitulus; M_1 joining R_5 nearly at right angles. Legs robust, the femora enlarged and the hind

femur curved; hind tibia as long as the hind femur; claws and pulvilli elongate in the male. Abdomen oval, pollinose; marginal rows of bristles on segments two, three and four fairly distinct; abdominal hairs sparse, erect; sternites all well formed in both sexes; ventral membrane widely exposed in the male, narrowly so in the female; sixth sternite of female shorter than the fifth; sheath narrow, pointed, closely appressed to the piercer, one-third longer than the sixth sternite; piercer sharp, narrow, pointing slightly upwards, just projecting beyond the sheath.

This genus which finds its closest ally in the European *Ilyalomya* is represented in North America by two species both of which are largely Western in distribution. These species may be separated as follows:

- Length 2.5-4 mm. Abdominal hairs sparse, arranged in four or five rows on each segment, the hairs with an inconspicuous black basal spot; bristles of tibiae fine.....*aldrichi* (Townsend)
 Length 5-6 mm. Abdominal hairs dense, in nine or ten rows on each segment, the hairs with a rather distinct black basal spot; bristles of tibiae very stout.....*robusta* n. sp.

***Ilyalomyiopsis aldrichi* (Townsend)**

Hyalomyia aldrichi Townsend, Proc. Ent. Soc. Wash., II, 136, 1891; type male, South Dakota (U.S.N.M.).

Hyalomyia celer Townsend, Trans. Amer. Ent. Soc., XXII, 65, 1895; type female, Las Cruces, New Mexico (Kansas). NEW SYNONYMY.

Phoranthia pruinosa Robertson, Can. Ent., XXXIII, 284, 1901; type male, Carlinville, Illinois (Illinois): NEW SYNONYMY.

Phasia cara West, Jour. N.Y. Ent. Soc., XXXIII, 123, 1925; type male, Karner, New York (Cornell): NEW SYNONYMY.

This species is probably the best known member of the complex and is the form most commonly determined as *Ilyalomya occidentis* Wlk. It is our smallest Phasiine.

Male. Length 2.5-4 mm. Antennae and arista black, the third antennal segment with greyish pollen; frontalia black; front, face, cheeks and occiput silvery grey, the occiput darker above; palpi dark brown.

Thorax black, the mesonotum subshining; humeri, disc of mesonotum and pleura very thinly greyish pollinose; pleural hairs black. Wings clear; veins brown or yellow; squamae white. Legs dark; tibial bristles short and weak.

Abdomen black; first segment except for a narrow posterior region, a small median spot on the anterior edge of segments two, three and four without pollen, the rest of the abdomen densely silvery-grey pollinose; abdominal hairs sparse, the hairs in three to five rows on each segment.

Female. Similar to the male; the thoracic pollen is more evident than in the male and the mesonotum shows four very faint vittae; abdomen coloured as in the male, the pollen grey or greyish-yellow, each hair with an evident shining spot at the base.

Distribution. ALASKA (Skagway, June 3); ALBERTA (Medicine Hat, Oct.; High River, Banff, Oct. 2; Lethbridge, May 22; Waterton, July 13; Morrin, June 4; Orion, Aug. 13; Kannanaskis, June 23); ARIZONA (Teme, June 19; Palmerlee); CALIFORNIA (Niles, May 9; Pacific Grove, May 10; Los Gatos, Feb. 16; Pasadena, April; Pleasanton, June 24; Redlands;

Tracy, Oct. 30); COLORADO (Boulder, Sept. 30; Grant, Aug. 20; Denver, Sept. 3; Greeley, Aug. 31; Ft. Collins; Canon City); DISTRICT OF COLUMBIA (Eastern Branch, Oct. 22); IDAHO (Moscow, July 15–Sept. 5; Kinghill, Sept. 29; Yale; Carey, Sept. 23; Juliaetta, June 5); ILLINOIS (Mason City, June 5); INDIANA (LaFayette, May 24–Oct. 22; Evansville, May 7; Michigan City); KANSAS (Garden City, Oct. 24); MANITOBA (Treesbank, July 13–Oct. 2; Aweme, Oct. 6; Teulon, July 7); MASSACHUSETTS (Melrose Hghds., June 19); MEXICO; MONTANA (Bozeman, Sept. 2); NEBRASKA (West Pt., Sept. 6–9; Partley, July 15; Indienola, July 5); NEW JERSEY (Atco; Woodbury, June 1–July 31; Bueno Vista, Nov. 6; Clementon, Oct. 6); NEW MEXICO (Socorro); NEW YORK (Karner, Nov. 4); NORTH DAKOTA (Bismarck, June 14; Lisbon; Minot, June 18); ONTARIO (Ottawa, May 15; Norway Point, July 15); SASKATCHEWAN (Swift Current, May 30; Saskatoon, May 23; Cypress Hills, June 5; Indian Head, July 7); SOUTH DAKOTA (Rapid City; Custer; Brookings; Pierre, May 22); TEXAS (College Station, July 11); UTAH (Logan Canon, June 6; Moab, Aug. 20); WASHINGTON (Spokane, July 7; Fishtrap Lake, Aug. 8; Pullman); WISCONSIN (Milwaukee, July 29).

***Hyalomyiopsis robusta* n. sp.**

Male. Length 5–6 mm. Head coloured as in *aldrichi*. Thorax black, the mesonotum subshining; humeri, posthumeral area and disc of mesonotum with evident grey pollen, the prescutum showing four very faint vittae. Wings clear; veins yellow; squamae white. Legs dark; tibiae bristled with long stout bristles. Abdomen black; the first segment (except a narrow central area posteriorly) and a narrow median spot on the anterior margins of segments two, three and four without pollen, the rest of the abdomen shining greyish pollinose; abdominal hairs comparatively dense, in nine or ten rows on each segment.

Female. Similar to the male except that the abdominal pollen is greyish or greyish-yellow and each hair has a black shining spot at the base.

Holotype. ♂, Summit Prairie, Grant Co., Ore., El. 5500 ft., VIII. 7. 41 (M. & R. E. Rider); in H. J. Reinhard's Collection, College Station, Texas.

Allotype. ♀, same data as type.

Paratypes. 2 ♂, 1 ♀, same data as type; 2 ♂, Lump Gulch near Gilpin, Colo., VIII.8.34 (N. Dondelinger and H. G. Rodeck); 1 ♂, Colorado, 25.VIII.31; 1 ♂, Boulder, Colo., VI.21.32 (M. T. James); 1 ♂, 1 ♀, Boulder, Colo., VI.5.32 (M. T. James); 1 ♂, Logan, Utah, VI.8.31, in Reinhard's Collection. 1 ♀, Clark Co., Kansas, June, 1962 ft. (F. H. Snow) in the Kansas University Collection. 1 ♂, Moscow, Idaho, IX.4.08 (J. M. Aldrich); 2 ♀, Moscow, Idaho, IX.5.08, on goldenrod, and VIII.26.12 (Aldrich); 1 ♀, Salt Lake, Utah, Oct. 20, 1913 (L. P. Rockwood); 1 ♂, San Diego Co., California; 1 ♂, Berkeley, Alameda Co., Calif., July 27, 1910 (J. C. Bridwell); 1 ♀, (Ft. Collins, Colo., 5.18.94 (J. H. Cowen), in the United States National Museum, Washington. 1 ♂, Ft. Collins, Colo., 7.30.15 (C. F. Baker) in the Museum of Comparative Zoology, Cambridge. Also one specimen from Ft. McLeod, British Columbia, Aug.

NORTH AMERICAN SPECIES NOT INCLUDED

Hyalomya occidentis Walker—Insecta Saundersiana, part IV, 260, 1856.

Mas: Atræ, caput argentatum; abdomen canum basi vittaque fascisque duabus nigris; alae limpidae

Deep black; head with a silvery covering; frontalia deep black, triangular; abdomen hoary, black towards the base and with a black stripe and two black bands; legs black; wings colourless; veins black, yellow towards the base and along the fore border; alulae white; poiser yellow. Length of body $2\frac{1}{2}$ lines (about 5 mm.); of the wings 5 lines. United States.

The description is closest to the Californian species *Paraphasia nigra* n. sp., described in this paper. Certain discrepancies as the "frontalia triangular," "wings colourless," and "alulae white" and the smaller dimensions make it advisable to leave the species as unidentifiable for the present.

Alophora luctuosa Bigot—Annales Soc. Ent. France, Dec. 1888, 255.

A. luctuosa, ♂, ♀, - Long. $4\frac{1}{2}$ mill - Undique nigro parum nitente; calyptis albido-flavido tinctis, halteribus fulvis; alis hyalinus base, anguste, pallido fulvo pictus - ♀, Simillima; fronte late fusco-nigro vittata - Amerique du Nord; montagnes Rocheuses, specim. 3 ♂, 1 ♀.

Coquillett recorded this species as a synonym of *occidentis* but the description indicates rather one of the *Alophorella* group.

REFERENCES

1. COQUILLETT, D. W. Revision of the Tachinidae: U.S.D.A. Div. Ent. Tech. Bull., No. 7, pp. 43-47. 1897.
2. CURRAN, C. H. Families and Genera of North American Diptera, p. 435. 1934.
3. GIRSCHNER, E. Wien Ent. Zeitg., V, pp. 1-6, 65-70, 103-107. 1886.
4. LUNDBECK, W. Diptera Danica, pt. VII, pp. 95-97. 1927.
5. MILLKEN, F. B. and F. M. WADLEY. Bull Brooklyn Ent. Soc., Vol. XVIII, pp. 28-31. 1923.
6. PAINTER, R. H. 60th Ann. Rept. Ent. Soc. Ont., p. 102. 1929.
7. ROBERTSON, C. Can. Ent., Vol. XXXIII, pp. 285-286. 1901.
8. TOWNSEND, C. H. T. Proc. Biol. Soc. Wash., Vol. XXVIII, pp. 19-24. 1915.
9. TOWNSEND, C. H. T. Manual of Myiology, pt. III, pp. 53-59, 1936; pt. VII, pp. 36-76. 1938.
10. VAN DER WULP, F. M. Tijdschr. v. Ent., XXV, 185. 1892.
11. VAN DER WULP, F. M. Biol. Centrali-Americana, Dipt., Vol. II, pp. 440-445. 1903.

AN APPRAISAL OF SPRAY MATERIALS FOR THE CONTROL OF APPLE SCAB IN ONTARIO¹

G. C. CHAMBERLAIN²

Dominion Laboratory of Plant Pathology, St. Catharines, Ontario

[Received for publication April 28, 1945]

For many years lime sulphur has been the standard fungicide for the control of apple scab. Its effectiveness as a preventive, eradicated, and adhesive spray has been demonstrated repeatedly. A serious limitation to its usefulness, however, is its tendency to induce foliage injuries detrimental to growth and yield. The extent of injury may vary in different localities and be influenced greatly by such factors as vigour of tree, method of spraying, dosage, and seasonal conditions. This danger of foliage injury has served to discredit lime sulphur for orchard spraying and has directed attention to the milder elemental or wettable sulphurs as possible substitutes. The present report concerns the results of spray trials with certain of these materials as well as with modifications of the Ontario spray calendar for apples.

MATERIALS AND METHODS

The experiments, commenced in 1939, were conducted at St. Catharines in the laboratory orchard comprising ninety-eight 11-year-old MacIntosh trees planted 28 feet \times 28 feet on a diagonal plan. The orchard has been subject to severe outbreaks of scab, and control proved difficult in seasons favourable for the development of the disease. Sprays were applied according to the development of buds, foliage, and fruit at the delayed dormant, pre-pink, calyx, and two cover sprays, as outlined in the Ontario spray calendar. Bordeaux 7½-15-100 was used for the delayed dormant spray, the differential spraying commencing with the pre-pink application. Arsenate of lead at recommended strength was added to all sprays. The following fungicides were used:

(1) *Commercial Lime Sulphur*, at the strength of 2½ gal. to 100 gal. of water with 7½ lb. hydrated lime, was used for the pre-bloom applications and at 2 to 100 for the calyx and 1st cover spray. For the 2nd cover application, Bordeaux 2½-5-100 was employed. In 1943 and 1944, the strength of lime sulphur was 1½ gal. to 100 (1-60).

(2) *Camden Flotation Sulphur Paste* (35% Sulphur). Flotation sulphurs are the most finely divided of all elemental sulphurs. Camden paste was used at the rate of 20 lb. to 100 gal. of water for the pre-bloom and calyx sprays and 12½ to 100 for the two cover sprays, with and without half strength lime sulphur in pre-bloom and calyx sprays. In 1944, the amount of flotation sulphur paste was 16 to 100 and 10 to 100 for the late sprays.

(3) *Koppers Dry Flotation Sulphur* (95% Sulphur). This flotation sulphur was used in 1943 at 7½ lb. to 100 gal. of water for the calyx spray and at 6 lb. for the 1st and 2nd cover.

¹ Contribution No. 816 from the Division of Botany and Plant Pathology, Science Service, Department of Agriculture, Ottawa, Canada.

² Associate Plant Pathologist.

(4) *Micro Flotox* (95% Sulphur). This is a sulphur prepared by the Micronizer process of grinding sulphur which results in a very finely divided product, next in fineness to that of the flotation sulphurs. It was used at the rate of 7 lb. to 100 gal. of water for the pre-bloom and calyx sprays and at 5 lb. for the cover applications.

(5) *Sulfuron* (97% Sulphur). This product, one of the group of elemental sulphurs of larger particle size than the foregoing, was used at the same rate as Micro Flotox.

(6) *Bartlett's Wettable Sulphur* (Micron sized 94% Sulphur). This product, reputed to approximate closely the fineness of micronized sulphur, was used at the same rate as Micro Flotox.

(7) *Kolofog Bentonite Sulphur* (30% Sulphur). This product, which consists of sulphur fused with bentonite, was used at the rate recommended by the manufacturers, 7½ lb. to 100 gal. of water, with and without weak lime sulphur for the pre-bloom and calyx applications.

(8) *Fermate*. This organic fungicide, containing 70% ferric dimethyl-dithiocarbamate as the active ingredient, was used at the rate of 2 lb. with an equal quantity of hydrated lime to 100 gal. of water.

(9) *Coposil* (20% copper). This so-called fixed copper was used in the 1st and 2nd cover sprays where summer oil emulsion was employed in the latter and 3rd cover spray for codling moth control. It was used at the rate of 2½ lb. to 100 gal. with 5 lb. hydrated lime added.

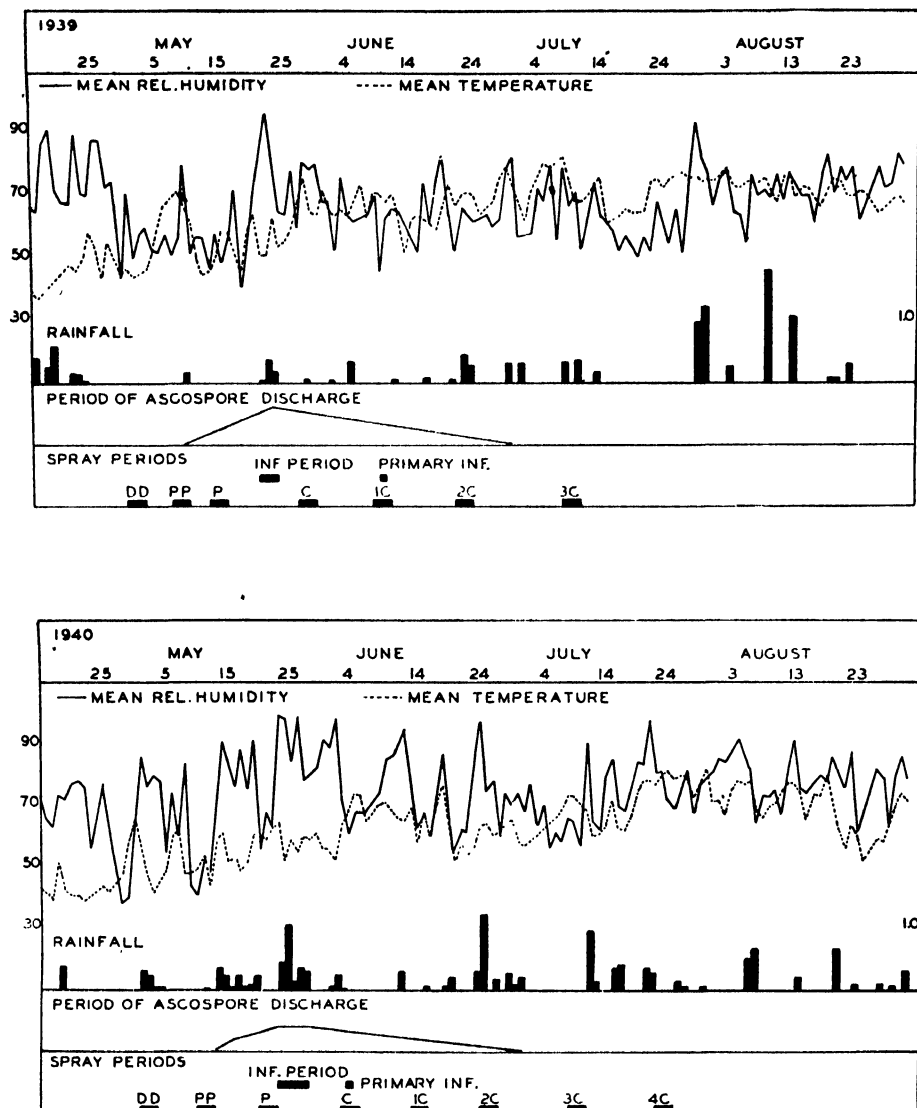
Orthex, a mineral oil type of spreader-adhesive, was added to certain sprays in 1943 and 1944 at the rate of 1 pint to 100 gal. of spray mixture.

Orvus (sodium lauryl sulphate) spreader, 1 pint to 100 gal., was added to certain sprays in 1943.

SEASONAL DEVELOPMENT OF SCAB

Meteorological data and information relative to the development of the apple scab fungus, host, and disease are shown graphically in Figures 1 to 3. The date of maturation of ascospores was ascertained by microscopical examination of overwintered scabby MacIntosh leaves, and the times and intensity of ascospore discharge were recorded by means of spore traps. Ascospore discharge, which occurs during rain, was found to extend from the latter part of April to the end of June; the period of major discharges occurred when the trees were either approaching or in full bloom. The distribution, amount, and duration of rainfall at this time were the important factors in determining the incidence of scab and the effectiveness of the sprays.

In 1939 and 1941, scab was of very minor importance. Both years were notable for a lack of rainfall in the early growing season, followed by comparatively dry summer weather. Only light scattered showers of short duration occurred during the period when the majority of ascospores were discharged, and consequently there was an absence of any serious infection. In 1939, very little scab was present in the orchard until August, when wet weather favoured the development of late infection on the fruit. In 1941, practically no scab occurred in the sprayed plots and only 3% of the fruit from unsprayed trees was infected.



EXPLANATION OF PLATES

FIGURE 1. Graphic summary of certain meteorological and seasonal data relating to apple scab in the Niagara Peninsula in 1939 and 1940.

In the remaining years, scab was very prevalent, no crop being harvested from unsprayed trees. Rainfall in May was excessive, with frequent showers followed by protracted periods of high humidity, especially at the peak of ascospore discharge. In 1940 and 1943, the critical infection periods occurred prior to bloom and were followed by the early establishment of the disease. This factor and inclement weather made control of scab very difficult. In 1942, the rainfall in May was even greater than in

1940 and 1943, but the infection periods were of shorter duration and occurred later in relation to host development. In 1944, little infection followed the more active ascospore discharges previous to bloom. However, the disease developed freely during the extremely damp weather of the late bloom period and spread rapidly with the recurring wet weather in June. Because of the prevalence of scab, it was deemed advisable to make an extra application of fungicides to all plots at the time of the 3rd cover spray (July 3).

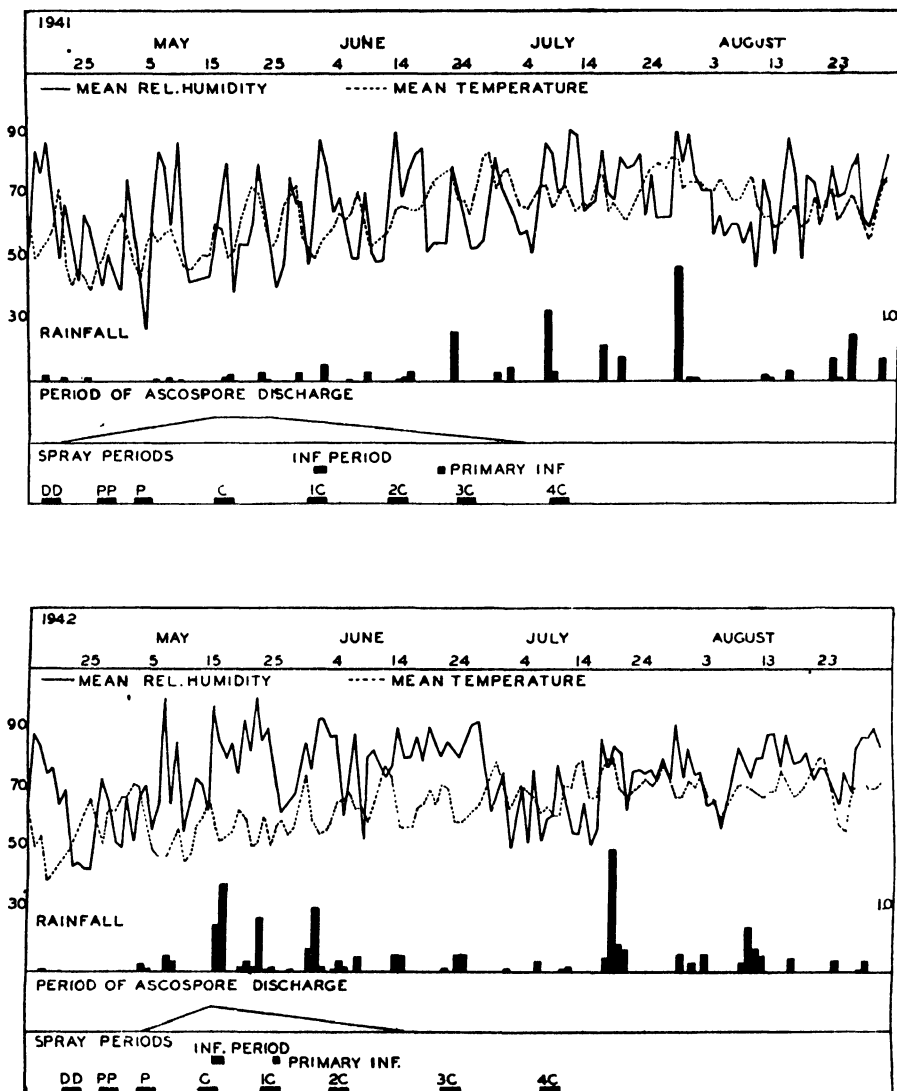


FIGURE 2. Graphic summary of certain meteorological and seasonal data relating to apple scab in the Niagara Peninsula in 1941 and 1942.

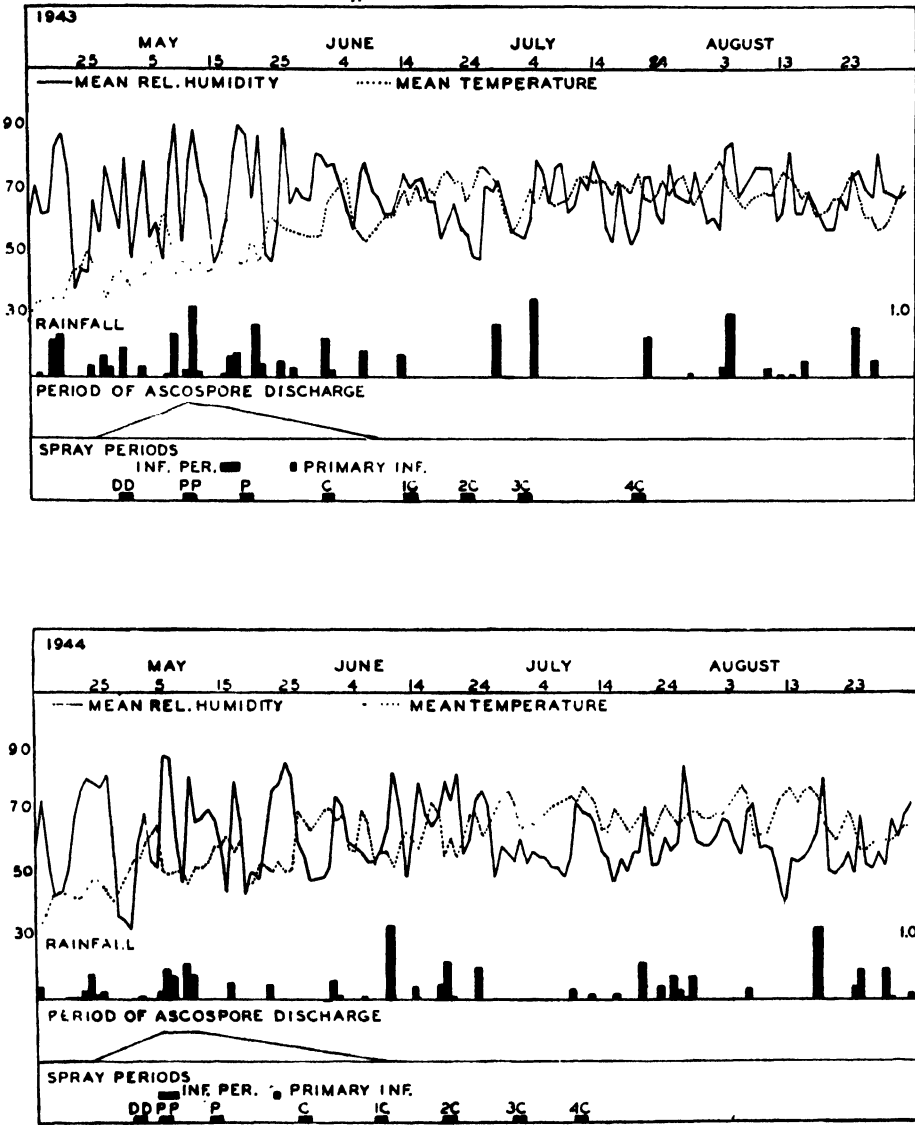


FIGURE 3. Graphic summary of certain meteorological and seasonal data relating to apple scab in the Niagara Peninsula in 1943 and 1944.

RESULTS OF THE EXPERIMENTS

In the spray trials of 1939-42, the same program was carried out annually, and the data obtained by examining the total crop harvested from each plot are summarized in Table 1.

TABLE 1.—RESULTS OF SPRAYING EXPERIMENTS AT ST. CATHARINES, 1939-1942

Spray treatment	MacIntosh apples with scab infection			
	1939	1940	1941	1942
	%	%	%	%
1. No sprays	51.3	94.8	3.6	94.1
2. Lime sulphur	4.7	10.9	T	2.9
3. Kolofog	24.0	71.7	T	12.3
4. Kolofog + lime sulphur 1-80	25.8	38.0	T	9.6
5. Flotation sulphur paste	11.6	28.6	0.0	7.2
6. Flotation sulphur paste + lime sulphur 1-80	8.6	13.5	0.0	5.6
7. Lime sulphur; Coposil; oil	3.0	5.6	0.0	1.5
8. Kolofog; Coposil; oil	7.4	11.6	T	3.0
9. Kolofog + lime sul. 1-80; cop.; oil	4.4	3.3	T	1.3
10. Flotation sulphur paste; cop.; oil	4.5	10.6	T	5.6

Lime sulphur 1-40 was the most effective in controlling scab, but it caused considerable foliage injury, especially in the wet seasons. The injury included dwarfing, distortion, marginal scorch, and tip-burn of leaves. In addition, lime sulphur increased the amount of yellow leaf and defoliation due to arsenical injury. Lime sulphur injury is important because it reduces the area and impairs the efficiency of the leaves. A number of investigators have studied its effect on growth and yield of trees. Burrell (1) reported a reduction of one-third in yield of trees sprayed with lime sulphur, as compared with wettable sulphur, and Rasmussen (4), a reduction of almost one-half. In this experiment, a lack of uniformity both in the size of the tree and in soil conditions rendered the crop and growth records unsatisfactory, and no direct evidence was obtained that the injury had a detrimental effect on tree performance. However, the deleterious effect of lime sulphur was clearly evident in thinner foliage, and smaller, distorted, and paler leaves.

The wettable sulphurs eliminated the danger of foliage injury but were less effective and less reliable than lime sulphur. Their fungicidal efficiency was influenced greatly by seasonal conditions, a fact clearly shown by the results obtained in 1940 and 1942. In 1940, when moisture conditions during the pre-bloom period were particularly favourable for scab, they proved of limited value. They gave much more satisfactory control in 1942, a season in which infection periods were of short duration and scab development was late in relation to host development (late bloom). The addition of $\frac{1}{2}$ strength lime sulphur to the wettable sulphurs for the pre-bloom and calyx sprays improved control of scab in 1940, but was of little value under the conditions existing in 1942. This combination spray, while not entirely eliminating lime sulphur injury, is considered warranted in seasons particularly favourable for the early development of scab.

Flotation sulphur paste was preferable to bentonite sulphur, especially under the severe conditions of 1940. The better performance of flotation sulphur emphasizes both the importance of high sulphur content in the spray and of fineness of sulphur particles in controlling scab. Flotation

sulphur paste was found much less convenient to use than the dry sulphur and required extra time and care to assure its proper dispersion in the spray tank.

Excellent control of scab was obtained where the various sulphurs were replaced with Coposil and Coposil in a 1% summer oil emulsion in the 1st and 2nd cover sprays. This treatment, in addition to its main purpose of reducing codling moth injury, has considerable merit in preventing late season infection of the fruit. However, the fruit had a somewhat inferior colour and finish in comparison with that of the other plots.

TABLE 2.—RESULTS OF SPRAYING EXPERIMENTS AT ST. CATHARINES, 1943

Spray treatments	Scab on harvested MacIntosh apples				
	No apples	Total scab*	Light	Medium	Severe
	No harvest	%	%	%	%
1. No sprays	4469	100.0	—	—	—
2. Lime sulphur 1-60	4080	31.7	15.9	6.9	9.0
3. Koppers dry flotation sulphur	3851	36.0	28.9	4.4	2.7
4. Sulfuron	3510	68.5	41.7	14.6	12.2
5. Kolofog	1423	83.5	26.4	24.9	32.2
6. Koppers dry flot. s. + Orthex	3365	14.3	12.2	1.2	0.9
7. Koppers dry flot. s. + Orvus	2941	30.7	25.7	3.0	2.0
8. Sulfuron + Orthex	4138	33.6	27.7	3.9	2.0
9. Sulfuron + Orvus	2771	48.6	37.5	6.8	4.3
10. Koppers dry flot. s.; Coposil: oil	2575	24.3	19.2	4.2	0.9
11. Sulfuron; Coposil: oil	732	34.3	22.1	7.2	5.0
12. Fermate + lime		30.2	29.0	0.8	0.4

* Scab infection was classified into three categories as follows:

- Slight — a single infection up to $\frac{1}{4}$ inch diameter or several pin-point lesions aggregating this amount.
- Medium — one or more lesions aggregating more than $\frac{1}{4}$ inch and up to $\frac{1}{2}$ inch diameter.
- Severe — numerous infections exceeding an aggregate of $\frac{1}{4}$ inch diameter or where fruit showed cracking or malformation due to scab.

The season of 1943 was favourable to the early and serious development of scab, and effective control was extremely difficult to attain.

Although, as indicated in Table 2, no treatment gave satisfactory commercial control, the results of the 1943 tests provide further evidence of the greater effectiveness of the finely divided sulphurs, represented by Koppers dry flotation sulphur. With this material, not only was there a smaller percentage of scabbed fruit but the fruit was less severely affected than that to which Sulfuron was applied at the same strength. Both Sulfuron and Kolofog were ineffective under the conditions prevailing in that year. With them, a high percentage of the fruit became seriously infected. These results further substantiate the previous conclusion that these types of wettable sulphurs are of limited value in seasons favourable to the early development of scab.

Much improved control of scab resulted from the addition of Orthex, a mineral oil spreader-adhesive, to the wettable sulphurs used for the calyx and cover sprays. This material, which appeared to improve coverage and to increase sulphur deposit on foliage and fruit, was superior to Orvus,

which added little to the control of scab, except when used with Sulfuron. Orvus was observed to foam considerably when agitated at high speed and did not show any special merit.

Lime sulphur, used at a weaker strength (1-60), caused moderate foliage injury and failed to show any advantage over dry flotation sulphur in controlling scab. A much higher percentage of the infected fruit from trees sprayed with the former was graded as culls than from trees sprayed with the latter.

The use of Coposil in place of the sulphurs in the cover sprays improved scab control, thus confirming previous results. However, a new development was the occurrence of a moderate to severe foliage spotting. Similar injury, attributed to the oil, was observed in other orchards. No explanation can be offered as to why this injury occurred.

The new organic fungicide Fermate proved very promising. In this plot, infection was relatively unimportant.

Another serious outbreak of scab was experienced in 1944, the infection developing very freely in the post-bloom period. An extra application of fungicides was made on all plots at the time of the 3rd cover spray and proved of the utmost importance in preventing the spread of the disease to the fruit.

TABLE 3.—RESULTS OF THE SPRAYING EXPERIMENTS AT ST. CATHARINES, 1944

Spray treatment	Scab on harvested MacIntosh apples				
	No apples	Total scab	Light	Medium	Severe
	No harvest	%	%	%	%
1. No sprays	2526	100.0	—	—	—
2. Lime sulphur 1-60	2897	10.1	7.9	1.5	0.7
3. Flotation sulphur paste	2209	9.6	8.5	0.8	0.3
4. Micro Flotox	3422	10.5	9.6	0.5	0.4
5. Bartlett's wettable sulphur	1082	30.8	21.9	4.3	4.6
6. Kolofog	2556	26.2	16.5	5.8	3.9
7. Micro Flotox + Orthex	2243	7.5	6.5	0.7	0.3
8. Bartlett's wett. s. + Orthex	1973	20.5	16.3	2.1	2.1
9. Sulfuron + Orthex	2187	21.9	18.3	2.5	1.1
10. Fermate	1954	3.2	3.1	T	T
11. Kolofog lime sulphur 1-80		10.9	9.6	0.9	0.4

The results in 1944 (Table 3) support those of previous years. In the plots sprayed with wettable sulphurs alone, the best control was obtained with those having the finest particles, namely, flotation sulphur paste and Micro Flotox. Orthex was of little value when used with micronized sulphur, but definitely improved the control obtained with the other materials. In this connection it should be pointed out that Orthex was added only in the pre-bloom and calyx applications. Since the latter and the subsequent cover sprays proved the more important in controlling scab, it might reasonably be assumed that even better results would have been obtained if Orthex had been added to the later cover sprays.

Fermate, with lime and Orthex, excelled all other treatments. The trees and fruit were outstandingly free from scab; but the trees showed more red mite injury and there was a greater infestation of the insect on the fruit at harvest than on the sulphur sprayed trees.

Lime sulphur 1-60 and the combination spray of bentonite sulphur plus lime sulphur 1-80 gave good control of scab, but in both cases considerable yellow leaf and defoliation developed after the calyx application. The defoliation was quite marked and a moderate scald of the fruit occurred. It was evident that the combination spray had little advantage over lime sulphur in respect to host injury.

SUMMARY AND CONCLUSIONS

These spray experiments demonstrate conclusively that lime sulphur 1-40 or 1-60 strength is the most effective fungicide for controlling scab, but cannot be considered "safe" under Niagara Peninsula conditions. Its use as an eradicant rather than a protectant spray might be warranted under conditions of severe outbreaks of scab or where such outbreaks are to be feared more than the occurrence of foliage injury. If lime sulphur is used, the strength recommended is that of 1-60, and when in combination with wettable sulphurs, 1-80, for the pre-bloom and calyx applications. For the post-bloom applications a wettable sulphur alone is preferred.

The milder elemental or wettable sulphurs possess the merit of "safety." They appear to have limited value in seasons favourable for early pre-bloom infection. They must be considered as protectant sprays, and when extremely wet conditions prevail in the early season, proper timing and adequate coverage are of the utmost importance in securing satisfactory results. Furthermore, experience suggests that, during prolonged wet periods, extra applications may be necessary.

Flotation sulphur, in dry or paste form, and micronized sulphur proved the most effective and most reliable substitutes for lime sulphur. Supporting evidence of the value of micronized sulphur was obtained in eight commercial orchards under observation outside the Niagara Peninsula, where it was used in 1944 and gave control of scab equal to that obtained with lime sulphur 1-60 or wettable sulphur plus lime sulphur 1-80.

Wettable sulphurs tend to adhere rather poorly. In this connection, the benefit of adding spreader-adhesive materials to the wettable sulphurs was demonstrated clearly in 1943. The addition of Orthex caused a flocculation of the spray suspension, and gave increased spray deposit as well as improved coverage and adhesiveness. This increased protection is particularly valuable under wet conditions at the time of the pre-bloom and calyx sprays, when the trees are most susceptible to infection.

Results were conclusive with respect to the special modification of the Ontario spray calendar recommended for orchards heavily infested with codling moth. This schedule, which employs copper in place of sulphur for the first and second cover sprays, was very effective in preventing fruit infection. However, from the standpoint of the colour and finish of the fruit, it was inferior to the regular sulphur schedules.

The results obtained with the new synthetic organic fungicide Fermate are of special interest. This fungicide has been under experimental observation in New York, Ohio, Virginia, British Columbia, and elsewhere for several seasons and has given results in the control of scab equal to or better than that obtained by the most effective of the wettable sulphurs. Tests in Virginia (6) have shown that it is compatible with summer oils, and thus it offers promise in the schedule for the control of codling moth. Recently other organic fungicides have been developed which in preliminary trials have shown great promise for the future. Some of these materials are reported (3, 5) to exhibit great specificity for certain diseases and to have therapeutic value, and their use is reputed to result in better sizing and colouring of the fruit. At the present time, they are not available for commercial use and no recommendation concerning them can be made.

REFERENCES

1. BURRELL, A. B. A six-year Comparison of Lime Sulphur and Flotation Sulphur as to Yield and Growth of Young MacIntosh Apple Trees. (Abst.) *Phytopath.* 33 : 2. 1943.
2. GROVES, A. B. Sulfur Sprays. *Va. Agr. Exp. Sta. Bul.* 359. 1944.
3. HAMILTON, J. M. et al. Tests with New Organic Fungicides on Orchard Fruits. (Abst.) *Phytopath.* 34 : 1002. 1944.
4. RASMUSSEN, E. J. Spraying and Orchard Practices Influencing the Yield and Quality of Apples. *Mich. Hort. Soc. 73rd Ann. Rept.* 1943.
5. WINTER & YOUNG. Puratized N5D, Fermate, and Methasan for the Control of Apple Scab and Bitter Rot. (Abst.) *Phytopath.* 34 : 1014. 1944.
6. WINTER & YOUNG. Information for Virginia Fruit Growers. *Va. Agr. Exp. Sta. Ext. Bul.* 131. 1933.

SOME STUDIES ON *MACROPHOMINA PHASEOLI* (MAUBL.) ASHBY IN ONTARIO¹

A. A. HILDEBRAND, J. J. MILLER AND L. W. KOCH²

Dominion Laboratory of Plant Pathology, Harrow, Ontario

[Received for publication May 30, 1945]

During the course of a plant disease survey in Essex County in south-western Ontario in August, 1944, a diseased soybean plant was found that exhibited symptoms strongly suggestive of Charcoal Rot. When minute sclerotia embedded in necrotic cortical tissue near the base of the stem of the affected plant were transferred to culture media, pure cultures of an organism subsequently found to be *Macrophomina Phaseoli* (Maubl.) Ashby were readily obtained. Prior to that time the presence of this pathogen on soybeans in Canada had not been known. Indeed, the only report of what may have been the same fungus on *any* host in Canada, is a brief notation in 1934 (3) citing the occurrence of *Sclerotium bataticola* Taub., on diseased fruits of pepper in Lincoln County, south, central Ontario. Hoffmaster and Tullis (6) have recently recorded that, in the United States, *Macrophomina* dry rot or charcoal rot, has been reported from 27 states, being found mostly throughout the southern half of the country, but it does occur as far north as Illinois and Indiana and has been recorded from Douglas County, Oregon. It is interesting to note that Douglas County, Oregon, and Lincoln and Essex Counties in Ontario, the three locations that, to date, mark the most northerly points in North America from which the pathogen has been reported, all lie just north of the 42nd parallel of latitude.

Concurrently with the isolation of *M. Phaseoli* from soybean, a second isolate that appeared to be almost identical with the first, was obtained from a diseased specimen of cotton that had been sent to the Harrow laboratory from Texas³. Not only on cotton but on many other hosts of outstanding importance, including corn and soybeans, charcoal rot is creating a problem of major pathological and economic significance in the United States. The two last-mentioned crops, corn and soybeans, are among those grown most extensively in Essex County. The presence of the pathogen having been established here, it seemed advisable to gain some further information not only about the fungus itself but also about its potential pathogenic capabilities especially as related to the two crop plants mentioned above.

DESCRIPTION OF THE DISEASE

Attention was first attracted to the soybean plant on which the disease was found by the fact that it had been prematurely killed and thus stood out conspicuously among the surrounding healthy plants. In removing the plant from the soil a strip of epidermis had been torn off the stem just above the crown thus exposing the light-coloured, necrotic, sub-epidermal tissue. Scattered thickly over the latter and appearing as small black specks were the sclerotia of the fungus (Figure 1). Sclerotia were not

¹ Contribution number 820, Division of Botany and Plant Pathology, Science Service, Department of Agriculture, Ottawa, Canada.

² Assistant Plant Pathologist, Agricultural Assistant and Pathologist-in-Charge, respectively.

³ Through the courtesy of G. E. Altstatt, College Station, Texas.

observed externally on the epidermis of the affected area of the stem. Another fungus disease commonly occurring on soybeans in Ontario, known as pod and stem blight, also very often attacks the plant towards the basal region of the stem. In the case of this latter disease, however, the minute, black, dot-like pycnidia of the causal organism, *Diaporthe Sojae* Lehm., are usually readily visible on the surface of affected areas and tend to be arranged in rows.

ISOLATIONS FROM DISEASED PLANTS

(a) *From Soybean*

On August 22, 1944, 64 individual sclerotia were transferred from freshly-exposed cortical tissues of the diseased field specimen to 16 plates of potato dextrose agar prepared according to the method of Riker and Riker (12). The agar in 8 of the plates had been acidified to the extent of two drops of 5% lactic acid per 15 ml. of medium while that in the remaining plates was left non-acidified. Four sclerotia were transferred to each plate.

In less than 17 hours, the sclerotia had germinated to the extent of approximately 100% and long filaments of mycelium were already permeating the medium. After 25 hours colonies averaging over one-half inch in diameter surrounded many of the sclerotia. A microscopic examination at 41 hours revealed that new sclerotia were developing profusely on all plates and at 65 hours myriads of these were visible to the unaided eye.

Since the above first attempt many additional sclerotia transferred to culture media from the original diseased specimen have never failed to germinate at ordinary room temperature and provide cultures that in turn developed sclerotia in abundance.

(b) *From Cotton*

In the course of making isolations from specimens of diseased cotton plants presumably affected with cotton wilt and from which it was expected to obtain cultures of *Fusarium vasinfectum* Atk., for use in certain comparative studies of *Fusarium*, there developed colonies of a sclerotium-producing fungus that closely resembled the one recently obtained from soybean. Because of their apparent similarity it was decided to use both in pathogenicity tests that were being planned. For convenience the isolates obtained from soybean and from cotton will be referred to as the Ontario and Texas strains, respectively.

INFECTION EXPERIMENTS

Series 1.—*Experiments in which stems of soybean plants were injured artificially and inoculated with the Ontario strain.*

On September 1, 1944, flap-type wounds were cut with a sharp scalpel in the cortical tissues at the base of the stem of healthy, 57-day-old soybean plants, variety A. K. Harrow, growing in pots in the greenhouse. Agar bearing mycelium and sclerotia of 8-day-old, mono-sclerotial cultures of the Ontario strain was inserted in the wounds which were then covered with moist absorbent cotton bound in place with adhesive tape. Check plants were treated in an exactly similar manner except that sterile agar was inserted in the wound. The number of plants involved, together with other relevant data and the results obtained are shown in Table 1.

TABLE 1.—RESULTS OF INFECTION EXPERIMENT INVOLVING ARTIFICIAL INJURY AND INOCULATION OF STEMS OF SOYBEAN PLANTS WITH ONTARIO STRAIN OF *M. Phaseoli*, SEPT. 1, 1944

Pot		Condition of stems		Final results			
No.	Plants	Nov. 7, 1944	Dec. 14, 1944	Mar. 13, 1945	Checks		Inoculated plants
					MP + *	MP - **	MP + MP -
1	Checks Nos. 1-3	All alive, healthy	All alive, healthy	All dead		3	
	Inoculated Nos. 1-3	1, 2 alive, healthy 3 dead	1, 2 dead—M.P. + S.†				2
							1
2	Inoculated Nos. 4-9	All alive, healthy	4 dead—M.P. + S.				1
			5-9 alive, healthy	5-9 dead—M.P. + S. + P.‡			5
3	Inoculated Nos. 10-15	10-13 alive, healthy 14-15 dead—M.P. + S.	10-13 dead—M.P. + S.				4
							2
4	Checks Nos. 4-9	All alive, healthy	4 alive, healthy 5-9 dead	4 dead		1	
						5	
5	Inoculated Nos. 16-18	16, 17 alive, healthy 18 dead—M.P. + S.	16-17 dead—M.P. + S.				2
							1
TOTALS						9	17
							1

* MP + S = *M. Phaseoli* present.
† MP + S = *M. Phaseoli* with sclerotia.
** MP - = *M. Phaseoli* absent.
‡ MP + S + P = *M. Phaseoli* with sclerotia and pycnidia.

If reference is made to Table 1 it may be noted that of 18 inoculated plants, 17 became infected whereas none of the 9 check plants showed any evidence of the disease. At 67 days after inoculation, only 4 of the inoculated plants had become infected. At 105 days after inoculation, an additional 9 inoculated plants had become infected. All plants examined at these two points showed only sclerotia of the fungus. On March 13, 1945, about 6½ months after inoculation, the last 4 inoculated plants had become infected and were showing *pycnidia of the fungus as well as sclerotia* scattered over the infected areas.

From the evidence it was clear that the plants had not become susceptible until they were approaching or had reached a condition of senescence. It was strongly suggested that the Ontario strain had acted as a facultative parasite. Once infection had taken place, its spread was rapid and in some cases sclerotia were visible on areas of the stems up to 9 inches in extent.

Series 2.—*Experiments in which seeds of corn and soybean were sown in soil artificially infested with the Ontario and Texas strains respectively.*

This series of tests was carried out in 3 Wisconsin tanks of 8-container capacity each, operated at 21°, 27° and 33° C., respectively. Containers and soil, the latter a mixture of 2 parts greenhouse compost and 1 part medium lake-shore sand, were sterilized with chloropicrin. The soil in 4 of the containers of each tank was infested with the Ontario strain of the organism, that in 2 others with the Texas strain, while that in the two remaining containers served as checks. Soil infestation was accomplished by addition of cornmeal-sand medium upon which the organism had been grown for 10 days, to the top 4 inches of soil in the containers, in the proportion of about 1½% by volume. The technique followed very closely that recently used with success by Miller (9). Non-disinfected seed of soybean variety A. K. Harrow and of corn inbred Hy, 15 seeds respectively per container, were used in the tests. Non-disinfected seed was used in order that results obtained might be compared with those of Semeniuk (13) who, in testing the susceptibility of corn inbred Hy to attack by *Sclerotium bataticola* Taub., used non-disinfected seed and also because in Series 1 the organism had exhibited such weak and delayed parasitic capability that it was felt the application of a fungicide to the seed might inhibit infection altogether.

Counts were taken daily of seedlings as they emerged. In Table 2, where final totals are recorded, it can be seen that differences in emergence are small and cannot be regarded as significant. As had been noted by Semeniuk (13) in his studies, no pre-emergent rotting of seed occurred in the infested soils. In the case of corn, maximum emergence took place on the 6th, 4th and 3rd days after planting, at 21°, 27° and 33° C., respectively.

TABLE 2.—PERCENTAGE EMERGENCE OF CORN AND SOYBEAN SEEDLINGS GROWN AT DIFFERENT TEMPERATURES IN INFESTED AND NON-INFESTED SOIL

Soil temperature °C.	Emergence of seedlings					
	Ontario strain		Texas strain		Check	
	Corn	Soybean	Corn	Soybean	Corn	Soybean
	%	%	%	%	%	%
21	100	86.6	100	100	100	86.6
27	100	96.6	100	86.6	100	93.3
33	100	100.0	100	100	100	93.3

Maximum emergence of soybean seedlings took place on the 5th day after planting at 21° and on the 3rd day at both 27° and 33° C.

(a) *Corn*

About the ninth day after planting, some of the corn seedlings in both inoculated and check soils at 33° showed a dying of the tips of the lower leaves, a general flaccidity, a necrotic condition of the stem just at the ground level and a badly rotted primary root system. Examination of and isolations from affected plants revealed the presence of *Fusarium moniliforme* Sheldon. Within 3 weeks, more heavily infected seedlings died, the number varying from 3 to 7 in the different containers at 33°. Seedlings apparently less heavily infected survived and together with those that seemed to have escaped infection developed into vigorous plants. Later, the same sequence, was observed in the 27° and 21° tanks but in less accentuated form and with lower mortality of seedlings.

Although the intrusion of *F. moniliforme* had defeated the primary purpose of the experiment i.e., an evaluation of the parasitic capability of the two *Macrophomina* strains, nevertheless, a representative number of the corn seedlings grown at the different temperatures was removed from the check and inoculated soils and examined microscopically. Mycelium and sclerotia of both strains were found as follows:

- (a) sparingly in necrotic tips of a few secondary roots at 33°.
- (b) frequently in decaying pericarp and mesocotyl tissues at 27° and 33°.
- (c) consistently and abundantly in coleoptile tissue (Figure 2) at all temperatures.

In most cases *F. moniliforme* was also present in the tissues examined, but from coleoptiles especially, both *Macrophomina* strains were readily re-isolated in pure culture. Even when coleoptiles were badly rotted and showed an abundance of sclerotia no evidence of spread of infection to underlying stalk tissues could be found. The evidence suggested that both strains should be regarded as facultative parasites, apparently being able to attack certain tissues of the corn plant only in their later stages of senescence. Such parasitic capability as they did exhibit was more readily apparent at 33° than at the lower temperatures. The isolate of *S. bataticola* used by Semeniuk (13) was perhaps a more aggressive parasite than those employed in the present studies. He reports that: "In most of the seedlings in the infested soil, necrosis was severe in mesocotyl and primary

root" and that, "Sclerotia were observed extending along the seminal roots as much as 8 cm. from the seed. The development of necrosis began at the seed and progressed for varying distances along one or all members of the primary root system and along the mesocotyl. Secondary roots became infected following complete necrosis of the mesocotyl during the early development of the seedling." In the present studies it was *F. moniliforme* that caused damage comparable to the above. Undoubtedly the seed used in the present studies carried in or on it a much greater amount of *F. moniliforme* or a much more aggressive and virulent strain of the pathogen than that used by Semeniuk. The latter investigator intimated that, "The activity of *S. bataticola* apparently was influenced considerably by the antibiotic activities of other soil organisms." Perhaps in the present studies *F. moniliforme* was present in such quantity as to greatly modify the parasitic capability of the two strains of *M. Phaseoli* under test.

(b) *Soybean*

Two weeks after the seeds were sown examination was begun of the soybean seedlings as they were removed from the check and inoculated soils, and whenever there was any evidence of a diseased or abnormal condition isolations were made and razor sections stained with acid fuchsin in lacto-phenol were prepared for microscopic examination.

No evidence of disease was found in roots of plants grown at 21° or 27° in either check or inoculated soil. After 3 weeks roots of plants grown at 33° developed in general a more or less distinct brownish discoloration and frequently root tips tended to become necrotic. Neither by isolation from nor by microscopic examination of selected material could the discoloration or necrosis be correlated with the presence of any particular organism and it was decided that they were evidence of reaction on the part of the plants to a soil temperature considerably in excess of that conducive to optimum growth.

On the underground portion of the stems of plants grown for 3 weeks at 27° and 33°, and for 5 weeks at 21°, in the soils inoculated with the two strains of *Macrophomina*, grayish areas varying both as to number and size, and contrasting more or less distinctly with the surrounding healthy tissue, became visible. Prepared sections of epidermal and sub-epidermal tissues showed the presence of *Macrophomina*. Incipient infections showed mycelium only or mycelium with sclerotia in earlier stages of development (Figures 6 and 7) while in older infections mycelium had for the most part disappeared leaving only mature sclerotia (Figure 5).

After surface sterilization of stems by immersing them for 30 seconds in a solution of ethyl alcohol and mercuric chloride (1 part 95% C_2H_5OH in 4 parts 1 : 1000 $HgCl_2$) and rinsing in sterile water, tissue plantings from grayish areas were made to acidified and non-acidified P.D.A. Apparently, such treatment was too drastic because nothing developed from the plantings. Thereafter, plantings were made to the culture medium following only thorough washing of selected portions of stems under running tap water using a camel's hair brush to facilitate removal of extraneous material. As a check, plantings were made also from presumably healthy tissue in close proximity to the affected areas. The results of the tissue transfers from the stems of 27 plants grown at the 3 different temperatures are summarized in Table 3.

TABLE 3.—SUMMARY OF RESULTS OF ISOLATIONS FROM INFECTED AND HEALTHY AREAS ON UNDERGROUND PORTIONS OF STEMS OF SOYBEAN PLANTS GROWN IN SOILS ARTIFICIALLY INFESTED WITH THE ONTARIO AND TEXAS STRAINS OF *M. Phaseoli*, RESPECTIVELY

Condition of stem	Number tissue plantings made	Plantings remaining sterile		Relative occurrence of organisms							
				Alternaria	Macro-phomina	Unidentified fungi	Bacteria	Fusarium	Mucor	Penicillium	Trichoderma
		No.	%								
Infected	90	—	—	% 28.8	% 73.3*	% 2.2	% —	% —	% 20.0	% 35.5	% 4.4
Healthy	70	22	31.4	32.5	19.8*	3.6	10.5	17.3	14.5	7.9	2.3

* Total for the two strains.

It may be noted from Table 3 that *Macrophomina* was isolated from infected areas on stems in much higher proportion than from apparently healthy adjacent tissue (73.3% as compared with 19.8%). At the time the isolations were being made it was noted that the representatives of the other genera of fungi recorded in Table 3 were obtained more frequently from larger, more distinct lesions that showed brownish-coloured necrotic tissue. All lesions, including the latter, remained relatively superficial. No stems were girdled and none of the plants with affected stems ever showed symptoms of disease on their above-ground parts. The grayish discoloured areas from which both strains of *Macrophomina* were consistently isolated often occurred within the zone of root proliferation. It was thought that fissures in the stem caused by the emergence of new roots might provide a convenient infection court. This possibility was carefully investigated but no confirmatory evidence was obtained. The two strains of the fungus appeared equally capable of producing the type of primary infection described above.

In the case of check plants grown in the uninoculated soil at 21° and 27°, the underground portion of the stems remained perfectly healthy. With the check plants grown at 33°, however, the underground portion of some stems showed indistinct, brownish-discoloured areas, from which *Alternaria* and *Penicillium* were sometimes isolated.

The above results indicate that in so far at least as one variety of soybeans is concerned, the two strains exhibit some slight degree of primary parasitic capability. They are aggressive enough to infect the epidermal and sub-epidermal tissues of the underground portion of the stem but possess sufficient virulence to cause only localized, superficial injury.

Series 3.—*Experiments in which stems of corn and soybean plants were injured artificially and inoculated with the Ontario and Texas strains respectively.*

In Series 2, a number of corn seedlings had died, as described above, following early attack by *F. moniliforme*. A considerable number also of both corn and soybean plants had been removed from the various containers in the 3 tanks for examination as to infection by *M. Phaseoli*. There still remained an appreciable number of each growing in the soils at the three different temperatures and it was decided to utilize them in a third series of stem inoculation studies. Consequently, using all available plants, the technique employed in Series 1 was repeated, the wounds being made as close to the soil level as possible. An 8-day-old plate culture of the Ontario strain obtained directly from the original field specimen served as a source of inoculum for the corn and soybean plants growing in the soil that in Series 2 had been inoculated with the same organism. Sixteen- and 21-day-old cultures of the Texas strain were used to inoculate the plants growing in the soil that had been already infested with that strain in Series 2. The inoculations were made January 13-15, 1945, when the plants were about 55 days old and they were left undisturbed until March 6. On the latter date all plants were removed from the containers and examined. The numbers of plants involved, their disposition and the results obtained are summarized in Table 4.

TABLE 4.—RESULTS OF INFECTION EXPERIMENTS INVOLVING ARTIFICIAL INJURY AND INOCULATION OF STEMS OF CORN AND SOYBEAN PLANTS WITH ONTARIO AND TEXAS STRAINS OF *M. Phaseoli*

Soil tempera- ture ° C.	Corn				Soybeans				Totals	
	Number and condition of				Number and condition of				Inoc- ulated plants	Check plants
	Inocu- lated plants	Check plants	Inocu- lated plants	Check plants	Inocu- lated plants	Check plants	Inocu- lated plants	Check plants		
	Ontario strain		Texas strain		Ontario strain		Texas strain			
33	3*/4**	0/3	0/6	0/4	4/12	1/7	0/6	0/4	7/28	1/18
27	3/7	0/4	1/8	0/5	3/13	1/8	0/7	0/4	7/35	1/21
21	1/7	0/5	0/9	0/5	0/15	1/8	0/8	0/5	1/39	1/23
Totals	7/18	0/12	1/23	0/14	7/40	3/23	0/21	0/13	15/102	3/62

* "Numerator" in each case denotes number of plants infected with *M. Phaseoli*.

** "Denominator" in each case denotes number of injured check and inoculated plants.

If reference is made to Table 4 it will be noted that altogether only 18 plants, 8 corn and 10 soybeans, became infected with *M. Phaseoli*. Since 16 of the 18 infected plants were growing in the warmer soils at 27° and 33°, and since the inoculations had been made at a point low enough on the stems to be within the zone of influence of heat radiated from the soil, it would seem that temperature might have been a factor influencing infection. It may be further noted that with a single exception all of the plants that became infected had been inoculated with the Ontario strain of the organism. This would suggest difference in specificity on the part of the two strains. From column 7 of the table, it will be seen that 3 of the check plants became infected. These were among plants grown in containers the soil of which had been inoculated with the Ontario strain in Series 2, so that infection likely took place from the soil.

Occurrence of sclerotia on the stems as revealed by examination with the dissecting microscope was the basis for determining infection of plants. If more critical methods had been adopted such as those employed by Weimer (14) the number of infected plants might have been found to be greater. Weimer noted that whereas some plants of *Chamaecrista* grown in soil infested with *M. Phaseoli* died in earlier stages of their development, others survived and showed little or no evidence of infection. When, however, such plants were disinfected and segments numbered from the root upwards were planted on agar plates, the fungus was recovered from many plants, sometimes from segments taken as high as 3 inches above the ground. Thus, it is possible that more than 15 (= 14.7%) of the 102 injured and inoculated corn and soybean plants—more especially, perhaps, those inoculated with the Ontario strain—may have been infected internally and that such infection might have become apparent if the plants could have been left to come to full maturity.

MORPHOLOGICAL AND CULTURAL CHARACTERISTICS OF THE ONTARIO AND TEXAS STRAINS

In the present investigation no attempt was made to study the two strains in complete detail. There were noted, however, certain morphological and cultural characters of each on which an accurate though limited, description and comparison may be based.

Mycelium

Comparison of the two strains on a basis of their mycelial characteristics was not attempted. In plate cultures on potato dextrose agar it was observed that the Texas strain differed from the Ontario strain in the presence of narrow-pyramidal tufts of flocculent aerial mycelium, grayish in colour near the surface of the medium and becoming lighter to almost white towards the apex of the tufts.

Pycnidia

Neither strain has produced pycnidia in culture or on the stalks of corn, tomato and soybean plants sterilized with steam. Apparently to date only in two instances both recorded by Haigh (4, 5) have pycnidia of *M. Phaseoli* been obtained in culture.

As mentioned earlier in the present paper, pycnidia did appear, however, on the stems of 4 soybean plants grown in the greenhouse, about 6½ months after they had been injured and inoculated with the Ontario strain of the fungus. When these plants were being examined under the dissecting microscope, it was noted that, scattered here and there among the more readily-recognizable sclerotia, were slightly larger black bodies that in contrast to the sclerotia appeared to be exerting pressure on and breaking through the epidermal tissues. These more conspicuous bodies were found to be pycnidia possessing an inconspicuous truncate ostiole and a membranous to subcarbonaceous wall. Globose to depressed globose in shape, they were found to vary from 100 to 200μ.

Conidia

(a) Shape and Size

The conidia are borne on simple, rod-shaped conidiophores up to 15μ in length, that arise from the entire inner surface of mature pycnidia. From Figure 3 it may be seen that the hyaline, non-septate, thin-walled conidia are variable in shape, oval or elliptical. Prominent in the granular contents of most of them are oil globules, one to several per spore. Two hundred spores in a suspension from 5 different pycnidia were measured and were found to range in length from 12.6 to 28μ, in width from 8.4 to 10.5μ, with a mean of $21.0 \times 9.3\mu$ for these two dimensions, respectively. Eighty-eight per cent of them were found to be between 18.9 and 25.2μ long while 85% were between 8.4 and 9.8μ wide. Ashby (1) comments that "The variations in spore size on the same host may be considerable, Shaw giving as a maximum range on jute in India, 16-29 × 6-11μ and Sawada for the same host in Formosa, 16-32 × 7-10μ; the dimensions fall mostly between 16-29 × 6-9μ."

(b) Germinating Capacity

Spores suspended in tap water or flooded on standard potato dextrose agar germinate in from 1½ to 2 hours at ordinary laboratory temperature

(Figure 4). Well-formed sclerotia were visible within 46 hours in colonies of mono-conidial origin growing in plate cultures on potato dextrose agar. Later when these sclerotia had reached maturity they were found to be indistinguishable from those produced in cultures originating from sclerotia taken directly from the host. Thus the genetical connection between the conidial and sclerotial stages of the fungus was definitely established by the pure-culture method.

In connection with the above it may be mentioned here that from 1924 when Wolf and Lehman (16) intimated briefly that "work is in progress on a root disease (of soybeans) with which *Sclerotium bataticola* is associated" until 1943, there are comparatively few references in North American literature to the incidence of charcoal rot on *soybeans*. During 1943 and 1944, however, many reports of the occurrence of the disease on this host in the United States have appeared. Of some 30 more recent reports consulted by the writers only in four of them (2, 8, 10, 11) is any mention made of the pycnidial stage, and in these the connection between the pycnidial and the sclerotial stage is apparently assumed on the basis of proximity of association of the two. Prior to the present studies the definite connection between the two stages of the organism occurring on soybeans does not seem to have been established by cultural methods.

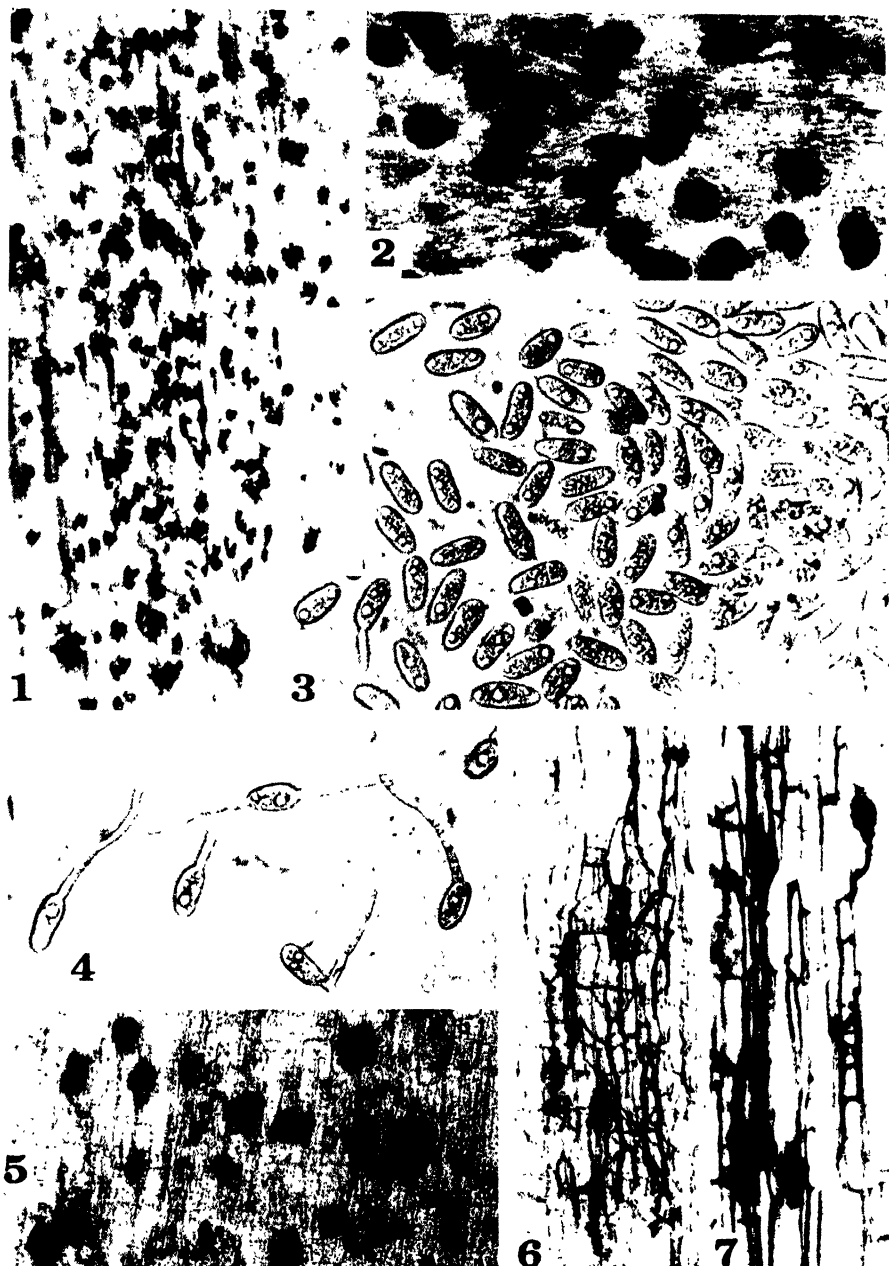
Sclerotia

(a) Shape and Size

The sclerotia of the two strains, small black, shiny bodies are indistinguishable microscopically. Their shape is modified slightly by the substratum in or on which they develop. In agar cultures or on the surface of stems they tend to be globular, oval or pear-shaped. In the cortical tissues of the soybean plant in which the Ontario strain was first noted most of the sclerotia were slightly flattened. In determining size of sclerotia it was found necessary to record their diameters on a two-dimensional basis. Over 1000 sclerotia of the two strains from both natural and artificial substrata were measured. Data in connection with these measurements are summarized in Table 5.

TABLE 5.—SIZE OF SCLEROTIA OF ONTARIO AND TEXAS STRAINS ON BOTH NATURAL AND ARTIFICIAL SUBSTRATA

Strain	Substratum	Sclerotia	
		No. measured	Average size
Ontario	Sub-epidermal tissue of original field specimen of soybean	155	Microns 89.6 × 74.8
Ontario	Peripheral zone of 25-day-old mono-sclerotial P.D.A. plate culture.	147	99.7 × 89.7
Ontario	Central zone of 25-day-old mono-sclerotial P.D.A. plate culture.	153	100.8 × 89.7
Ontario	Random selections from 25-day-old mono-conidial P.D.A. plate culture.	150	99.4 × 88.9
Ontario	Stem of inoculated, greenhouse-grown soybean plant.	155	91.3 × 76.8
Texas	Peripheral zone of 25-day-old mono-sclerotial P.D.A. plate culture.	143	84.8 × 72.2
Texas	Central zone of 25-day-old mono-sclerotial P.D.A. plate culture.	150	86.1 × 73.8



Mycelium, pycnospores and sclerotia of *M. Phaseoli*. FIGURE 1. Sclerotia of Ontario strain in cortical tissues of naturally-infected field specimen of soybean (X12). FIGURE 2. Sclerotia of Ontario strain in coleoptile of corn (X70). FIGURE 3. Pycnospores of Ontario strain (X400). FIGURE 4. Germinating pycnospores of Ontario strain after 2 hours in tap water (X400). FIGURE 5. Sclerotia of Texas strain in sub-epidermal tissues of stem of soybean (X70). FIGURES 6 and 7. Incipient infection by Ontario strain in stem of soybean showing mycelium and sclerotia in early stage of development (X70).

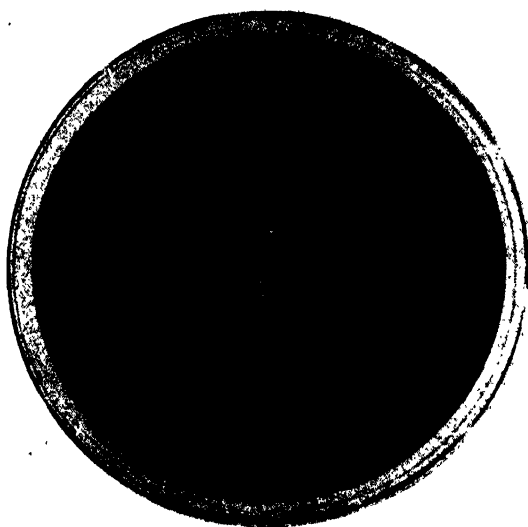


FIGURE 8. Twenty-six-day-old cultures of Ontario (left) and Texas (right) strains of *M. Phaseoli* on potato dextrose agar.

If reference is made to Table 5 it may be noted that the sclerotia of the Ontario strain on the original field specimen of soybean and on the stems of inoculated plants in the greenhouse measured $89.6 \times 74.8\mu$ and $91.3 \times 76.8\mu$, respectively, with an average size of $90.4 \times 75.8\mu$. On P.D.A. plate cultures, sclerotia of the same strain whether of monosclerotial or mono-conidial origin, averaged $99.9 \times 89.4\mu$. Thus, the Ontario strain produced larger sclerotia on the artificial medium than on the natural substratum. On P.D.A. plate cultures, sclerotia of the Texas strain averaged $85.4 \times 73.0\mu$. Thus, they are appreciably smaller than those of the Ontario strain on the same substratum. Not only are they smaller but they occur in greater numbers per unit area or volume of medium. The effect of this greater density of smaller sclerotia is that the Texas strain appears much darker in colour than the Ontario strain. As is clearly shown in Figure 8, this may be of diagnostic significance.

(b) Germinating Capacity

On frequent occasions from August, 1944, until April, 1945, sclerotia from the original *Macrophomina*-infected field specimen have been transferred to plates of both acidified and non-acidified P.D.A. Over this 8-month period the sclerotia have never failed to germinate quickly and to the extent of practically 100%. In making the transfers it was noted that small bits of plant tissue often adhered to a sclerotium. Thus, it would not seem impossible that in an appreciable number of cases the organism might originate not from the sclerotium but from the adhering plant tissue. To investigate this possibility, 25 minute particles of freshly exposed sub-epidermal tissue in close proximity to sclerotia were transferred to plates of acidified P.D.A. from the infected field specimen. In not a single instance was there any development of fungal growth.

In a second test, 25 sclerotia were transferred to acidified P.D.A. from host material after it had been immersed for 30 seconds in an alcohol-mercuric chloride solution (1 part 95% C_2H_5OH to 4 parts 1:1000 $HgCl_2$) and rinsed in sterile water. Within 24 hours over 90% of the sclerotia had germinated. In a third test the period of immersion was increased to 60 seconds and in this case only 3 of a total of 25 sclerotia germinated. The results of the above three tests indicate that capacity for germination is inherent in the sclerotia themselves.

Sclerotia of both strains grown on artificial media have shown weak and erratic capacity for germination as compared with those taken directly from the field specimen. Furthermore, there seems to be correlated with increasing age in culture a decreasing capacity for germination on the part of sclerotia of both strains. These statements are based on evidence obtained as follows. Fifty sclerotia of the Ontario strain obtained directly from the infected field specimens and 50 sclerotia of each of the two strains taken from 11-, 21-, and 31-day-old P.D.A. cultures, were transferred to plates of P.D.A. (25 sclerotia per plate) and incubated at $27^\circ C$. The plates were examined at definite intervals and germination counts taken, with results as shown in Table 6.

An examination of Table 6 reveals the following points: (a) all the sclerotia taken directly from the field specimen germinated within 18 hours; (b) whatever the source, no sclerotia germinated after 42 hours;

TABLE 6.—COMPARISON OF GERMINATING CAPACITY OF SCLEROTIA FROM THE HOST AND FROM ARTIFICIAL CULTURES OF DIFFERENT AGE

Test	Strain	Source of sclerotia	Number of sclerotia examined	Germination of sclerotia					
				Periodic Increments					Total
				18*	26	42	66	90	
				%	%	%	%	%	
1	Ontario	Soybean, field specimen	50	100	—	—	—	—	10
	Ontario	11-day P.D.A. culture	50	38	14	6	0	0	58
	Texas	11-day P.D.A. culture	50	34	8	2	0	0	44
2	Ontario	Soybean, field specimen	50	100	—	—	—	—	100
	Ontario	21-day P.D.A. culture	50	24	10	6	0	0	40
	Texas	21-day P.D.A. culture	50	18	6	9	0	0	33
3	Ontario	Soybean, field specimen	50	100	—	—	—	—	100
	Ontario	31-day P.D.A. culture	50	16	8	6	0	0	30
	Texas	31-day P.D.A. culture	50	0	0	0	0	0	0

* Hours after transfer.

(c) sclerotia of the Ontario strain exhibited a consistently higher capacity for germination than those of the Texas strain; (d) increasing age of culture had a depressing effect on the germinating capacity of both strains, the effect being more marked, however, in the case of the Texas strain.

IDENTIFICATION OF THE ONTARIO AND TEXAS STRAINS

Ontario Strain

On a basis of the morphological characters of its pycnidia, conidia and sclerotia, on both natural and artificial substrata, the Ontario strain can be definitely identified as *Macrophomina Phaseoli* (Maubl.) Ashby.

Texas Strain

Although the pycnidial stage of this strain was not observed, nevertheless, measurements of sclerotial diameter in culture were all, in their means, under the minimum of 120μ permitted for inclusion in Haigh's (5) group C, indicating their similarity in respect of size to the fungi recorded from many widespread areas as *Macrophomina Phaseoli*.

The designation of the isolates from soybean and from cotton as strains of *M. Phaseoli*, throughout the present paper, is justified, if not on a basis of their specific host preferences, then on the differences in their morphological and cultural characters to which attention has been directed.



DISCUSSION

In 1931, after reviewing the literature relating to the parasitism of *M. Phaseoli*, West and Stuckey (15) stated that, "As the evidence stands, there is not sufficient proof in any direction. Thus Small and Reichert have obtained positive infection experiments. Hansford and Weir report negative results. The American workers on the other hand describe inoculations indicating weak parasitism." Following their own compre-

hensive studies of the parasitism of *M. Phaseoli* on cotton and jute, the above-mentioned workers concluded that under normal conditions the fungus is not a parasite but that under very moist conditions it will attack jute seedlings. They found further that cotton plants growing in soil deficient in humus may become susceptible to *M. Phaseoli* during a definite period and that under controlled conditions young cotton plants are susceptible to the organism for a certain period of time after artificial defoliation. They found that with defoliated cotton plants, there is a certain correlation between susceptibility and the presence or absence of starch in the tissues. They were led finally to conclude that *M. Phaseoli* is a facultative parasite, such parasitic capability as the organism does display being bound up with the physiology of the host, the host and its environment being implied.

In general, the findings and conclusions of the present writers tend to be more closely in accord with those of West and Stuckey than with those of several other investigators. In the first series of tests in which stems of soybean plants growing in the greenhouse were artificially injured and then inoculated with the isolate of *M. Phaseoli* obtained from soybean, infection appeared and spread rapidly only after the plants had reached the later stages of senescence. Here, infection seemed correlated primarily with physiological changes within the host rather than with any particular factor of the environment. In the second series of tests in which corn and soybeans were grown in sterilized soil artificially infested with isolates of *M. Phaseoli* obtained from soybeans and from cotton, respectively, under controlled conditions at temperatures considered optimum and above and below optimum for these plants, the impression was strengthened in so far at least as corn was concerned that such parasitic capability as the two isolates did display was of the facultative type, their attack on certain tissues (pericarp, mesocotyl, coleoptile) being associated with the senescence or near senescence of these tissues. In attacking the underground portion of the stems of soybean plants and producing superficial, grayish-coloured areas of infection, the two strains displayed definite, though limited, capability as primary parasites. Since infection appeared two weeks earlier on the stems of plants grown at 27° and 33° than on those grown at 21° C., temperature was undoubtedly one of the factors interacting with others in the host-pathogen-environment complex. The correlation between temperature and infection was more clearly indicated in Series 3 where, of a total of 18 plants (8 corn and 10 soybeans) that became infected, 16 (= 88.8%) were growing in the warmer soils at 27° and 33° C. Referring in this connection to work done elsewhere, it may be pointed out that in 1933 Kendrick (7) reported that in California epiphytotics of a destructive stem blight of seedling beans caused by *M. Phaseoli* in its sclerotial stage coincided with the emergence of seedlings during or immediately following periods of 10 days or more with a mean air temperature of 80° F. or above and a daily maximum of about 100°. In connection with inoculation tests involving bean seedlings grown in pots of sterilized inoculated soil Kendrick states, "The results show that *Rhizoctonia bataticola* may cause a destructive blight of seedling beans and thus corroborate the theory suggested by the field observations, i.e., that high temperatures are necessary for infection."

In the present studies it was found that sclerotia of the isolate from soybean produced in culture showed weak and erratic capacity for germination as compared with those taken directly from the infected field specimen. Moreover, sclerotia of both strains showed an apparent loss of viability that increased with age in culture. Sclerotia from a 31-day-old culture of the cotton isolate showed complete loss of viability. In the papers consulted by the present authors no reference has been found to this phenomenon of loss of viability of sclerotia of *M. Phaseoli* in culture. To date no attempt has been made to determine its cause. Its detection suggests that only young cultures should be used as source of inoculum in pathogenicity tests. In a series of 10 experiments Haigh (5) injured and inoculated the stems of 495 plants representing several different genera and species, with isolates of *M. Phaseoli* obtained from sources as widely separated as Ceylon and the United States. In the first 8 experiments, of 359 plants involved only 43 (= 11.9%) became infected. In the last two experiments, 136 plants were injured and inoculated and 97 (= 71.3%) became infected. In the last two experiments Haigh used as inoculum mycelium of 2- and 3-day old cultures. Unfortunately he gives no indication of the age of the inoculum employed in the first 8 experiments. If he had happened to use older cultures that might be one reason why such a relatively small number of plants became infected. It should be pointed out that in the two sets of experiments as indicated above, there was "overlapping" not only of the same host plants but also of the isolates of the fungus used as inoculum. Haigh comments, "The fungus *Macrophomina Phaseoli* has been shown to be extremely plastic in culture. It may be that a similar plasticity in its pathological reaction will account for the inconsistency of experimental results obtained by the present writer and others." Could "plasticity" in the pathological action of the fungus in some cases be accounted for by the use of inoculum that, differing in age, differed correspondingly in the viability of sclerotia of which in part at least it must have been composed?

Semeniuk (13) found that "the activity of *S. bataticola* apparently was influenced considerably by the antibiotic activities of other soil organisms" and Weimer (14) drew attention to the fact that "the pathogenicity of the fungus on the same host is quite variable in different localities."

From the foregoing it may be adjudged that a study of the pathogenicity of *M. Phaseoli* on a particular host could and probably would involve consideration of a number of entirely different yet closely inter-related factors. The present studies have indicated that if, for example, the host were soybeans then such factors as age not only of plants to be inoculated but also of the inoculum to be used and soil temperature would have to receive especial consideration.

SUMMARY

Two isolates of *Macrophomina Phaseoli*, one (the Ontario strain) obtained locally from a field specimen of soybean exhibiting typical symptoms of charcoal rot, the other (the Texas strain) from a diseased cotton plant from Texas, have been compared morphologically and tested as to their pathogenicity on soybean (variety A. K. Harrow) and corn (inbred line Hy).

When stems of soybean plants growing under ordinary conditions in the greenhouse were artificially injured and inoculated with the Ontario strain, the latter acted as a facultative parasite, showing ability to infect the plants only as they approached senescence. Pycnidia as well as the more-commonly-occurring sclerotia were produced on a few plants.

When corn and soybeans were grown at controlled temperatures of 21°, 27° and 33° C., in sterilized soil inoculated with the respective strains, such parasitic capability as both strains displayed was, in the case of corn, of the facultative type. In attacking the underground portion of the stems of soybeans and producing thereon characteristic, grayish-coloured areas of infection, the two strains displayed definite, though limited, capability as primary parasites. Infection appeared earlier on plants grown at the two higher temperatures.

When under controlled conditions similar to the above, the stems of corn and soybean plants were injured and inoculated at the soil level with the two strains, of a total of 102 inoculated plants 15 (8 corn, 7 soybeans) became infected. Fourteen of the latter were among those grown at 27° and 33°, thus reaffirming a correlation between temperature and infection. Since 14 of the 15 affected plants had been inoculated with the Ontario strain, there was a suggestion of host specificity on the part of the latter. Parasitism in all cases was of the facultative type.

In culture neither strain produced pycnidia but these did appear on certain of the greenhouse-grown soybean plants inoculated with the Ontario strain. Pycnidia and conidia are described. Cultures of mono-conidial origin produced the sclerotial stage. Thus, by the pure culture method was established for the first time the genetical connection between the two stages of *the organism occurring on soybean* and on the basis of the morphology of its pycnidia, conidia and sclerotia it was definitely identified as *M. Phaseoli*.

The two strains have been differentiated on the basis of difference in size and number of sclerotia produced in culture. Sclerotia of both strains showed an apparent loss of viability that increased with age in culture. In marked contrast, sclerotia from the original soybean herbarium specimen showed no loss of viability after 8 months.

The parasitism of *M. Phaseoli* in relation to certain biotic and abiotic factors has been discussed.

REFERENCES

1. ASHBY, S. F. *Macrophomina Phaseoli* (Maubl.) comb. nov. the pycnidial stage of *Rhizoctonia bataticola* (Taub.) Butl. Trans. Brit. Myc. Soc., 12 : 141-147. 1927.
2. ATKINSON, R. E. Diseases of soybeans and peanuts in the Carolinas in 1943. U.S. Dept. Agr. Plant Disease Reporter, Supplement 148 : 254-257. 1944.
3. CONNERS, I. L. Diseases of vegetable and field crops. Thirteenth Ann. Rept. Canadian Plant Disease Survey, p. 29, 1933. 1934.
4. HAIGH, J. C. *Macrophomina Phaseoli* (Maubl.) Ashby. The pycnidial stage of *Rhizoctonia bataticola* (Taub.) Butl. Tropical Agriculturist, 70 : 2. 1928.
5. HAIGH, J. C. *Macrophomina Phaseoli* (Maubl.) Ashby and *Rhizoctonia bataticola* (Taub.) Butler. Ann. Royal Botanic Gardens, Peradeniya, 11 : 213-249. 1930.
6. HOFFMASTER, D. E., and E. C. TULLIS. Susceptibility of sorghum varieties to *Macrophomina* dry rot. U.S. Dept. Agr. Plant Disease Reporter, 28 : 1175-1184. 1944.
7. KENDRICK, J. B. Seedling stem blight of field beans caused by *Rhizoctonia bataticola* at high temperatures. Phytopathology, 23 : 949-963. 1933.

8. LARSH, H. W. Diseases reported on soybean in Oklahoma. U.S. Dept. Agr. Plant Disease Reporter, 28 : 1010. 1944.
9. MILLER, J. J. Studies on the *Fusarium* of muskmelon wilt. I. Pathogenic and cultural studies with particular reference to the cause and nature of variation in the causal organism. Can. J. Research, C, 23 : 16-43. 1945.
10. PERSON, L. H. Report on diseases of soybeans—Mississippi. U.S. Dept. Agr. Plant Disease Reporter, 27 : 509. 1943.
11. PRINCE, A. E. Soybean diseases in South Carolina. U.S. Dept. Agr. Plant Disease Reporter, 28 : 1125. 1944.
12. RIKER, A. J. and RIKER, R. S. Introduction to research on plant diseases. John S. Swift Company, Inc., St. Louis, Missouri. 1936.
13. SEMENIUK, G. Seedling infection of dent maize by *Sclerotium bataticola* Taub. Phytopathology, 34 : 838-843. 1944.
14. WEIMER, J. L. *Macrophomina* root and stem rot and anthracnose of *Chamaecrista*. Phytopathology, 34 : 1077-1085. 1944.
15. WEST, J. and W. R. STUCKEY. *Macrophomina Phaseoli* (Maubl.) Ashby in Trinidad. Part I. Parasitism. Part II. Physiology. Mem. Imp. Coll. Trop. Agr. Trinidad (Mycol. Ser.) 4 : 22 pp. 1931.
16. WOLF, F. A. and S. G. LEHMAN. Soybean diseases. 47th Ann. Rept. N.C. Agr. Expt. Sta., pp. 82-83. 1924.

A SEED DISPENSER—DEVICE FOR MEASURING SEED BY VOLUME FOR ROD ROW PLOTS¹

C. H. GOULDEN²

Dominion Laboratory of Cereal Breeding, Winnipeg, Manitoba

[Received for publication June 7, 1915]

The device described was developed in order to speed up and reduce the work of packaging seed for rod row plots.

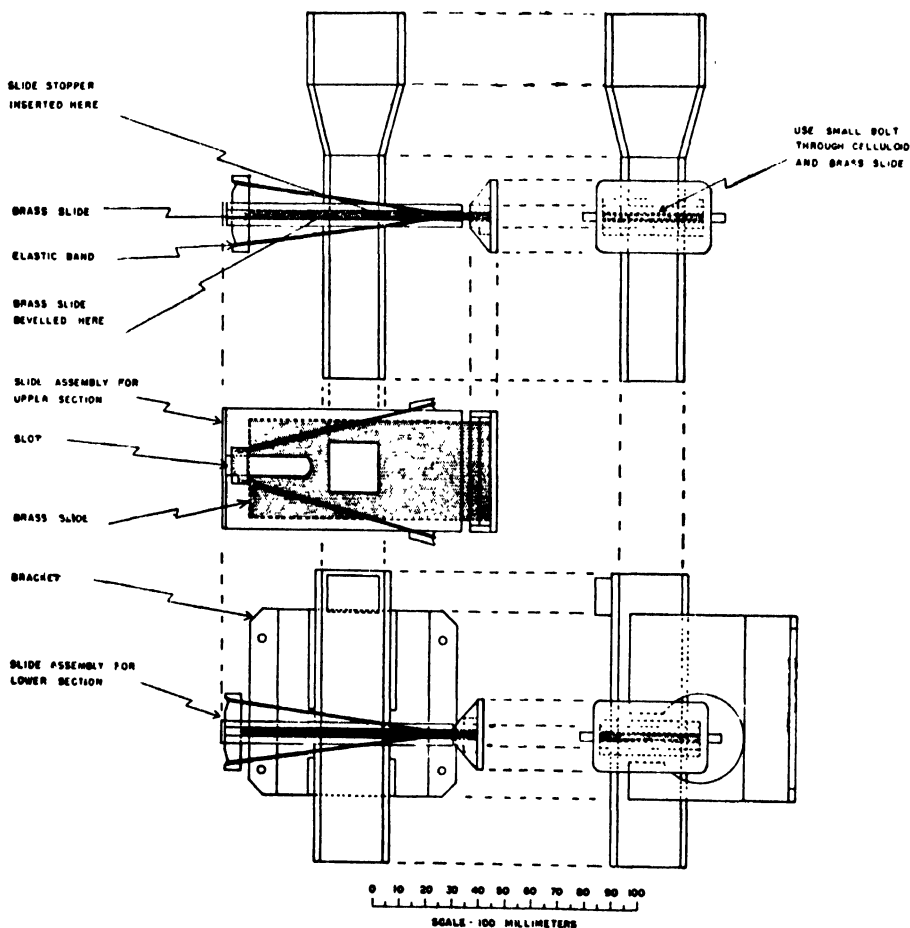


FIGURE 1. Details of construction of seed dispenser

In order to make rod row plots of different varieties or treatments comparable they should be sown as nearly as possible with the same number of germinable seeds. Previous to the development of the seed dispenser, the procedure followed at this laboratory was first to determine experimentally the average weight of the number of seeds required and then to weigh out the seed for each package. This method was slow and measure-

¹ Contribution No. 134 from the Cereal Division, Dominion Department of Agriculture.

² Senior Agricultural Scientist.

ment by volume using cups of varying sizes to dip out the seed was found to be much faster and nearly as accurate as weighing. The next logical step was to make a device that would measure volumes of seed quickly and accurately. After trying various designs the one described was found to be very satisfactory. A number of these have been manufactured at the Central Experimental Farm at Ottawa under the direction of Mr. J. G. C. Fraser, for distribution to Dominion Experimental Stations in Canada.

DESCRIPTION

The basic principle of the device is extremely simple. There is an upper and a lower section of square tubing. The upper one slides inside of the lower one and in each section there is a slide to open up or cut off the flow of seed. Rubber bands hold the slides closed. Pressure on the upper slide allows the seed to flow through and fill up the tube as far as the lower slide. The upper slide is then released and the required volume of seed is then contained in the tube between the two slides. Pressure on the lower slide allows the seed to flow out and on releasing the lower slide the machine is ready for the next load. The volume of seed measured is adjusted by sliding the upper tube in and out of the lower one.

Figure 2 illustrates the seed dispenser in use showing the stand to which it is attached and the large tin funnel which holds the bulk seed. The dispenser slides are operated with two fingers of one hand leaving the other hand free to place envelopes under the delivery spout and to remove them when filled. Envelopes containing sufficient seed for one rod row plot can be filled at approximately 300 per hour.

Details of construction are given in Figure 1. Dimensions can be obtained from the drawing by reference to the millimeter scale. The dimensions are not critical as there is sufficient adjustment to allow for constructional variations. The particular machine described is designed for use with wheat, oats, and barley. A somewhat smaller machine would be more suitable for flax and a larger one for peas or beans.

The material used for the framework of the seed dispenser is sheet celluloid approximately 2.5 millimeters thick. Canadian Industries Limited supply this material under the trade name of Pyralin. The exact thickness of the material is not critical but it should not be less than 2 millimeters as thin material will warp badly in warm weather. Material thicker than 2.5 millimeters is rather difficult to work. The celluloid parts are welded by means of a cement with an acetone base. A satisfactory cement is 40% amyl-acetate and 60% acetone.

Celluloid has distinct advantages as compared to metal for making devices of the kind described. It is more easily cut and welded and its transparency is an advantage in a device such as the seed dispenser where it is desirable to be able to watch the flow of seed.

Two details should be added that are not shown in Figure 1. In the first place it is necessary in order to have sufficient range for the measurement of wheat, oats and barley to make a square inner tube about 40 millimeters long to fit inside of the tube of the upper section. Normally this will be used when measuring wheat but will be out for oats and barley.

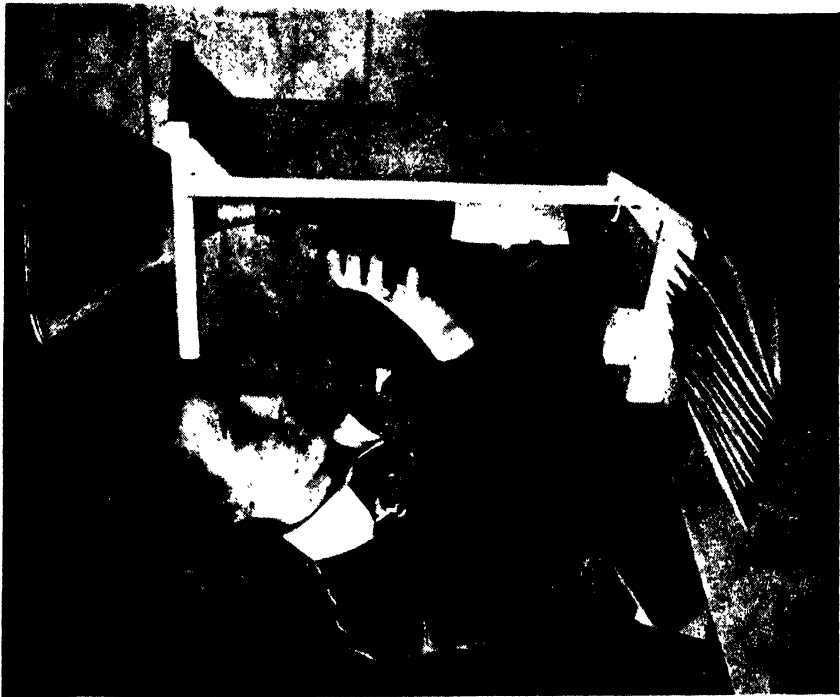


FIGURE 2. Seed dispenser in operation

In the second place a suggestion made by Mr. J. G. C. Fraser should be incorporated. This is a threaded rod with a knob or knurled head at one end, for adjusting the volume. A rod of about $3/16$ inches in diameter is suggested. The best arrangement seems to be to attach the rod by means of collars to the lower slide assembly and thread it through a portion of the upper slide assembly. Additional celluloid strips can be welded to the slide assemblies for this purpose. In the model shown in Figure 1, adjustments were made by means of a set screw in the block of celluloid shown attached to the lower section. This method is not entirely satisfactory as the set screw tends to push the tube of the upper section out of shape.

Anyone who has not handled sheet celluloid would be well advised before starting to build one of the seed dispensers, to practise for a short time at cutting and welding. The material can be cut by scoring deeply and then breaking. The edges must then be filed smooth before fitting the parts together. The cement is applied freely to the parts to be welded and these are held firmly in place until the cement has hardened.

ACKNOWLEDGMENT

The original models were made by W. A. Clark, now Flt. Sergeant W. A. Clark, Photographic Establishment, Rockcliffe, Ottawa. He was responsible for making and trying out various designs.

IDENTIFICATION OF GRAIN SAMPLES OF HARD RED SPRING WHEAT VARIETIES GROWN IN WESTERN CANADA¹

R. F. PETERSON², A. J. LEJEUNE³ AND H. C. LAIDLAW⁴

[Received for publication June 20, 1945]

It is frequently necessary for those engaged in the production, handling, marketing, grading or testing of grain, either as commercial grain or as seed, to be able to identify samples as to variety. Several years ago instruction on this subject was instituted as part of an agricultural short course given annually by the Division of Plant Science of the University of Manitoba, and the writers were asked to prepare a suitable outline for hard red spring wheat. This was provided in the form of a mimeographed table. As requests for copies of this table have been received from time to time from individuals and from groups interested in wheat, it was thought desirable to publish it.

The outline was prepared originally for the use of farmers, several men employed in the grain trade and others engaged in grain grading and seed testing, all of whom attended the above-mentioned course. The purpose of the outline is to provide a rapid visual method of identifying grain samples of hard red spring wheat varieties commonly occurring in Western Canada, involving a minimum of measurement or statistical work.

MATERIALS AND DEVELOPMENT OF METHODS

The varieties selected for study are listed with their Canadian Accession Numbers in Table 1. Renown and Regent are resistant to stem rust and

TABLE 1.—SPRING WHEAT VARIETIES AND CROSSES FROM WHICH THEY WERE DERIVED

Variety	Canadian accession number	Cross from which derived
Marquis	1396	Hard Red Calcutta × Red Fife
Reward	1509	Marquis × Prelude
Renown	1915	H-44* × Reward
Regent	1938	H-44* × Reward
Thatcher	1820	(Marquis × Iumillo) × (Marquis × Kanred)
Apex	1857	(H-44 × Double Cross†) × Marquis
Garnet	1316	Preston A × Riga M
Red Bobs	1637	Selected from Early Triumph which appeared to be from a natural cross between Bobs (white-kerneled) and a red-kerneled variety.

* H-44 was derived from the cross Yaroslav Emmer × Marquis.

† Double Cross was derived from the cross (Marquis × Iumillo) × (Marquis × Kanred).

leaf rust: Thatcher and Apex are resistant to stem rust only; and the remaining varieties are susceptible to both rusts. Excellent publications (1, 3, 4, 5) are available dealing with identification of these varieties using the main characteristics of the plant as a whole including the grain. A comprehensive review of literature on identification of wheat species and varieties is given by Clark and Bayles (1).

¹ Joint contribution from the Cereal Division, Experimental Farms Service, Dominion Department of Agriculture; the Division of Plant Science, University of Manitoba; and the Crop Testing Plan, Winnipeg, Manitoba. Published as Paper No. 135 of the Cereal Division, Experimental Farms Service.

² Senior Assistant Agricultural Scientist, Dominion Laboratory of Cereal Breeding, Winnipeg, Manitoba.

³ Lecturer, Division of Plant Science, University of Manitoba.

⁴ Assistant Director, Crop Testing Plan, Winnipeg, Manitoba.

Four of these wheats (Marquis, Reward, Garnet and Red Bobs) were included in studies of eleven varieties by Fraser and Gfeller (2) dealing with phenol reactions of spikes and kernels, and with a number of morphological characteristics of kernels. These authors dealt with depth and length of kernel, length of germ, and the angle at which the germ is set, pointing out that in Garnet wheat the germ is "set into the body of the kernel at a more acute angle than any other common wheat usually associated with it in the trade in Canada."

It should be noted here that some of the rust resistant wheats have been modified by selection since they were described in the publications mentioned above. The strain of Regent originally distributed and described was C.A.N. 1902 whereas the strain now commonly grown is C.A.N. 1938. (The corresponding accession numbers at the Dominion Laboratory of Cereal Breeding, Winnipeg, are R.L. 975.1 and R.L. 975.6). C.A.N. 1938, developed from a single plant selection of C.A.N. 1902, has a smaller, smoother kernel than the latter and produces samples of better colour and higher weight per measured bushel. Further improvement in colour and weight per measured bushel has been made by reselection within C.A.N. 1938. A new foundation stock accessioned at Winnipeg as R.L. 975.26 and at Ottawa as C.A.N. 3616 is expected eventually to replace C.A.N. 1938 in the country.

The original Renown C.A.N. 1856 (known also as R.L. 716) was replaced in a similar manner by the selection C.A.N. 1915 (R.L. 716.6) which was superior in leaf rust resistance, strength of straw, yield and quality, but in this case there was little change in kernel characteristics except for greater uniformity.

The stocks of Thatcher and Apex now grown in Western Canada are also more uniform in kernel characteristics than those originally distributed.

As the present study was confined to visual examination of the grain it was found necessary to make use of a larger number of kernel characteristics than is normally used in identification of the plant as a whole. Therefore in preparing the outline presented in this paper a large number of samples grown in Western Canada over a period of years was studied. In some cases complete sets of the eight varieties listed in Table 1 were grown under comparable conditions and samples were available for study.

In addition, a collection of samples was provided by Mr. F. S. Ludlam, Chief Grain Inspector, Inspection Branch, Board of Grain Commissioners for Canada, Winnipeg. Mr. Ludlam greatly assisted in pointing out the grain characteristics which he and his staff had found most useful in identification work, and a number of these have been incorporated in the present outline.

The main difficulties met with in this work were due to (a) the close genetic relationship of most of the varieties and (b) the effect of environment on grain characteristics. As shown in Table 1, the first six varieties consist of Marquis and its derivatives. Accurate identification within this group is often difficult, but it is usually relatively easy to recognize samples of the remaining two wheats, Garnet and Red Bobs. Environment affects all kernel characteristics, causing a range of variation within varieties; and

these varietal ranges overlap to a great extent. This is illustrated strikingly in a coloured plate of Marquis kernels presented by Newman and Fraser (3). In addition to ordinary variations in soil and climate from district to district, disease, drought, or poor growing conditions of any kind tend to obscure varietal differences. However the use of a combination of a relatively large number of characteristics for identification work reduces markedly the uncertainty of identification due to obscure or overlapping characteristics.

Wheat varieties can be identified more easily and accurately from whole plants or heads than from grain samples alone. The methods which follow are therefore intended for use only when nothing but grain samples are available for study.

IDENTIFICATION OF WHEAT SAMPLES

Table 2 presents the outline prepared for use in identifying wheat samples and Figure 1 shows photographs giving four views of representative kernels of each variety. Accurate identification depends mainly on experience and familiarity with the material. The outline presented here cannot take the place of such experience but can only serve as an aid and a guide. It is therefore recommended that, for all varieties discussed above, samples of known identity as well as the photographs in Figure 1 be examined with reference to Table 2 before attempting to use this table to identify unnamed samples. At first all varieties should be examined and compared with respect to individual characteristics, e.g. seed colour. Next the characteristics of each variety are studied collectively. With sufficient experience of this kind, a composite mental picture of the characteristics of grain samples of each variety will be developed, and rapid identification work becomes possible. At the best, however, a degree of error will always remain due to the difficulties already enumerated.

Because of the use for which Table 2 was originally intended the writers have purposely avoided the use of measurement. In presenting such quantitative terms as "short," "mid-long," etc., without defining them in terms of actual units of measurement, it is assumed that the operator will examine samples of known identity and set up approximate mental standards. In the study of length of kernel, for example, average Garnet or Renown samples will be taken as "mid-long" and average Red Bobs or Marquis samples as "short." These concepts then become the standards in dealing with samples of unknown identity. This method has been found practicable because the people for whom the outline has been prepared are already familiar in a general way with the range of variation of colour, kernel size, etc. of wheat samples produced in Western Canada.

Definitions of the various quantitative terms in units of measurement are given by Clark and Bayles (1). The terminology of the present paper will be found to agree in general with that of these authors. Differences will be found to occur, however, because of the two publications being based on samples grown in different environments.

The description of Regent given in Table 2 holds equally well for C.A.N. 1938 and the newer Foundation Stock C.A.N. 3616.

TABLE 2.—KERNEL CHARACTERISTICS OF COMMON WHEAT VARIETIES
(Characteristics most useful in identifying varieties are set in italics)

Variety	Colour	Length and width	Shape	Germ	Crease	Brush	Checks	Remarks
Marquis	Medium red	<i>Short</i> , wide	Ovate, <i>brush end truncate</i> (cut off)	Mid-size	Mid-deep, mid-wide	Mid-size, short to mid-long	Usually rounded, sometimes angular	<i>Short, plump kernel. Slight hump on back, behind germ. Indistinct longitudinal ridge along one side of back.</i>
Reward	Darker than Marquis, almost bronze	Short to mid-long, wide	Ovate, <i>brush end truncate</i>	Mid-size, <i>blunt angle</i>	Shallow, narrow	Small, short	Rounded to angular	<i>Slightly longer than Marquis. Distinct longitudinal ridge on one side of back continuing to form shoulder over germ. Crease side usually flat due to crease being closed.</i>
Renown	Medium red	Mid-long, mid-wide	Ovate	Mid-size	Shallow, narrow	Mid-size, mid-long	Rounded to angular	<i>Less distinct ridge on one side of back. Crease side usually flat as in Reward.</i>
Regent	Medium red	Mid-long, mid-wide	Ovate, brush end truncate	Mid-size	Shallow, wide	Mid-size, mid-long	Angular	<i>Like Renown but ridge on back less distinct, crease more open, and kernel less smooth.</i>
Thatcher	Medium red, dull, bleached appearance	Short, mid-wide	<i>Ovate but almost oval</i>	Small to mid-size	Mid-deep, wide	Mid-size, short to mid-long	Angular, edge often whitish	<i>Well-grown samples sometimes have a silvery sheen; others often whitish. Collar around brush. Kernel more nearly oval than in the other varieties.</i>
Apex	Medium red	Mid-long, mid-wide	Ovate	Mid-size	Mid-deep, mid-wide	Mid-size, mid-long	Rounded to angular	<i>Like Marquis but lighter colour, longer, more tapered at brush end, and less uniform in size. Pointed projection at germ end.</i>
Garnet	<i>Very deep red</i>	Mid-long, narrow	Ovate to elliptical	Large square, <i>sharp angle</i>	Mid-deep, mid-wide	Small, mid-long	Rounded to angular	<i>Back straight to depressed or only slight hump. Crease side curved from end to end. (Kernels short and truncate in some districts).</i>
Red Bobs	<i>Light red</i>	<i>Short</i> , wide	Ovate to oval, <i>truncate ends</i>	Large	Mid-deep, mid-wide to wide	Mid-size, short	Usually rounded, sometimes angular	<i>Short, plump kernel. Truncate at both ends. Back usually rough. Samples often contain small deformed kernels. Pit often formed in crease.</i>

DISCUSSION OF INDIVIDUAL CHARACTERISTICS

Colour

There is a wide range from the light red of Red Bobs to the very deep red of Garnet. The name of the latter variety describes its colour very well. Renown has the most translucent and Thatcher the most opaque kernel. The Thatcher kernel commonly has a whitish or grayish colour (as though bleached) combined with the medium red basic colour, although fresh samples grown under the best conditions have a silvery sheen.

Length and Width

Although length and width of kernel vary considerably with different growing conditions, the ratio of length to width is much more constant. This ratio is lowest in Marquis and Red Bobs and highest in Garnet. In badly shrunken kernels all varieties tend to have a high length-width ratio.

In average size of kernel Garnet and Thatcher are smallest and Regent largest.

Shape

The kernels are mostly ovate (egg-shaped) being broader at the germ end than at the brush end, but the tendency of Thatcher kernels to be oval (with equal width at both ends) aids in identifying this variety.

Germ

The germ area is medium in size and tends to be round or oval in shape in most varieties, but is larger and inclined to be somewhat square in Garnet. The angle the germ makes with the longitudinal axis of the kernel is, on the average, sharpest in Garnet and most blunt in Reward. The pointed projection at the end of the germ is most prominent in Apex and least in Red Bobs.

Crease

The depth and width of crease varies greatly within varieties due to different growing conditions. On the average the crease is most closed in Reward and Renown, and most open in Thatcher and Regent. In all varieties a pit is occasionally found in the crease, but it is most common in Red Bobs.

Cheeks

Both rounded and angular cheeks are found in all varieties but the rounded cheek is most commonly found in Marquis, Garnet and Red Bobs. The angular cheek and the whitish line on the edge of the cheek are more frequently found in Thatcher than in the other varieties. Any condition that reduces the plumpness of kernel in wheat varieties tends to produce angular cheeks.

Brush

Although the area of brush and length of brush hairs vary within varieties, average varietal differences are sufficiently constant to be useful in identification work. The collar around the brush is most prominent in Thatcher, but a less distinct collar may be found in some samples of the other varieties.

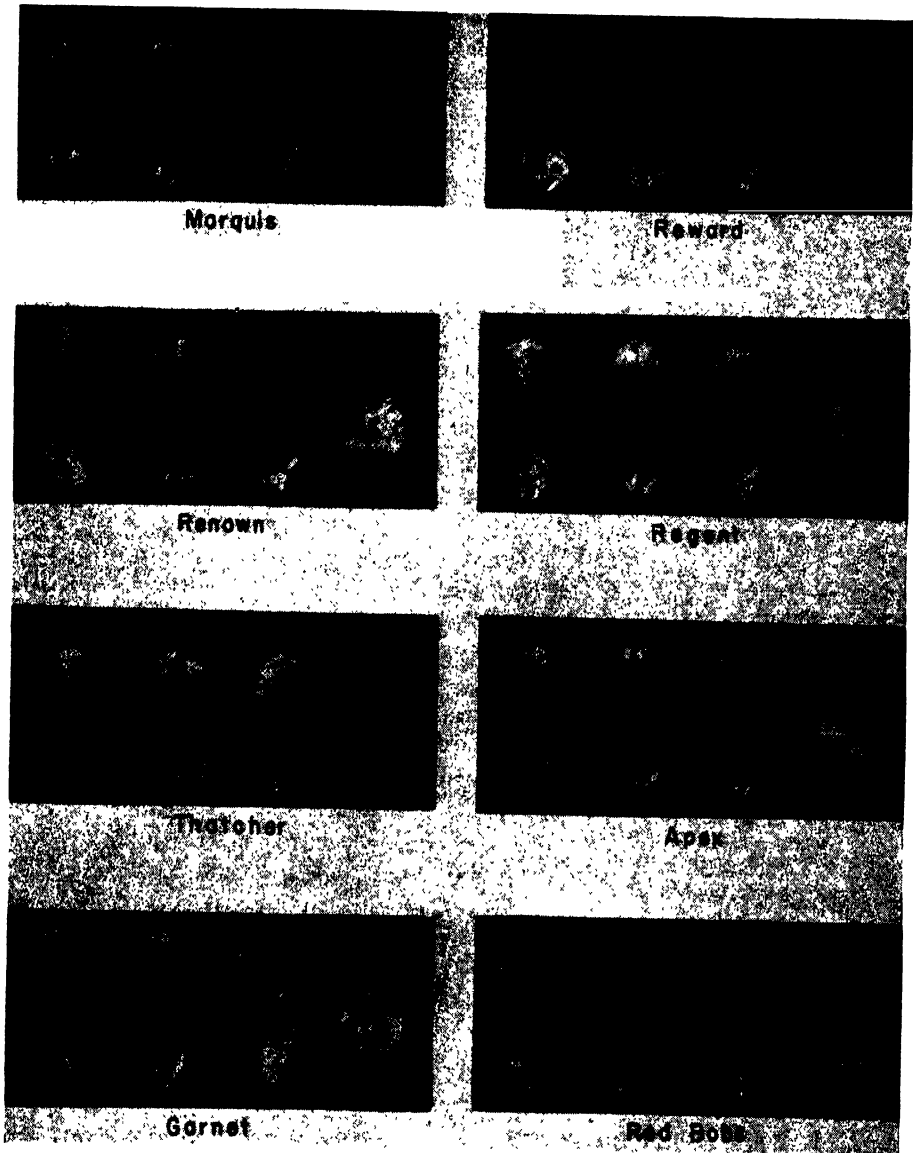


FIGURE 1. Dorsal, ventral, lateral, and cross-sectional views of representative kernels of eight hard red spring wheat varieties.

Back

The position of the relatively sharp longitudinal ridge along one side of the back of Reward and Renown kernels is clearly shown in Figure 1. A less distinct one-sided development of the back is characteristic of the other varieties. However, all eight varieties display a sharp ridge if the kernels are somewhat shrunken.

The back of Red Bobs kernels is usually comparatively rough.

SUMMARY

A non-technical outline is presented to aid those engaged in the wheat industry to identify, as to variety, grain samples of hard red spring wheats commonly grown in Western Canada.

It is suggested that a preliminary examination of samples of known varieties with reference to the outline will enhance the operator's ability to use it in identifying samples of unknown identity.

ACKNOWLEDGMENTS

Grateful thanks are extended to Mr. F. S. Ludlam, Chief Grain Inspector, Inspection Branch, Board of Grain Commissioners for Canada, Winnipeg, for making available his collection of wheat samples, and for valuable suggestions as to varietal characteristics useful in identifying grain samples.

The writers are indebted to Victor G. Martin of the Grain Research Laboratory, Board of Grain Commissioners for Canada, Winnipeg, for making the photographs of wheat kernels shown in Figure 1.

The helpful suggestions of Dr. L. H. Newman, Dominion Cerealist, in the preparation of the manuscript, are gratefully acknowledged.

REFERENCES

1. CLARK, J. ALLEN and B. B. BAYLES. Classification of wheat varieties grown in the United States in 1939. U.S.D.A. Tech. Bul. 795. 1942.
2. FRASER, J. G. C. and F. GFELLER. Two new methods of distinguishing certain Canadian wheats. *Sci. Agric.* 15 : 564-572. 1935.
3. NEWMAN, L. H. and J. G. C. FRASER. Marquis wheat. Description of the standard type. Dominion of Canada Dept. of Agric. Pamphlet No. 95, New Series, 1928.
4. NEWMAN, L. H., J. G. C. FRASER, and A. G. O. WHITESIDE. Handbook of Canadian spring wheat varieties. Dominion of Canada Dept. of Agric. Publ. 538 (Farmers' Bull. 18), Revision. 1939.
5. NORTHWEST CROP IMPROVEMENT ASSOCIATION. Dictionary of spring wheat varieties. Minneapolis, 1941.

EFFECTS OF CULTIVATION AND CROPPING ON THE CHEMICAL COMPOSITION OF SOME WESTERN CANADA PRAIRIE PROVINCE SOILS. PART III¹

J. D. NEWTON², F. A. WYATT³, AND A. L. BROWN⁴

University of Alberta and Dominion Experimental Farms Service

[Received for publication June 1, 1945]

Soil deterioration has always been a problem in agriculture because maintenance of soil fertility is essential for any system of permanent agriculture.

Comparatively few actual determinations of the extent of the losses of soil organic matter in the Prairie Provinces of Canada had been made prior to the initiation of this investigation, although it is recognized that soil organic matter is the main natural source of available plant food, that it increases the moisture holding capacity of soils, reduces or prevents erosion by wind or water (if fibrous) and otherwise improves the physical properties of soils. It was decided that the extent of the losses *should* be determined because the future of agriculture in these provinces, including the satisfactory rehabilitation of soldier farmers following the cessation of hostilities, depends largely upon maintenance of soil fertility. An extensive investigation was therefore undertaken to determine by chemical analysis of some cropped and virgin soils what effects the present methods of farming have had on the organic matter of the soil, and on some total and available or easily soluble plant foods.

Farming practices have been very similar over wide areas of the three prairie provinces. They consist mainly of grain and fallow systems said by many to be wasteful of soil fertility.

Reference was made in the first paper in this series (3) to evidence obtained in Britian, the United States, and Canada, of losses of nitrogen and organic carbon from soils resulting from cultivation and cropping.

Recently DeTurk (4) reported that on the Morrow plots at Illinois, with continuous corn, corn-oats rotation, and corn-oats-red clover rotation, during the past 29 years the organic carbon of the surface soil had remained practically constant on both the fertilized and unfertilized plots of the 3-year rotation. A similar constancy occurred on the fertilized portion of the 2-year rotation. In the other plots the organic carbon was found to undergo a progressive decline. Total nitrogen was found to follow the organic carbon rather closely. Total phosphorus also declined more under continuous corn than under a corn-oats rotation or a corn-oats-clover rotation.

Malzer (7, 8) in Kansas studied the influence of cropping systems and soil treatments on the nitrogen and organic carbon of soils. Losses occurred in some rotations and under continuous wheat, but alfalfa grown continuously increased the soil's supply of nitrogen and organic carbon over a period of 19 years.

¹ Contribution from Dominion Department of Agriculture, Experimental Farms Service, P.F.R.A., in co-operation with the University of Alberta, Department of Soils.

² Professor of Soils.

³ Professor of Soils.

⁴ Research Assistant, P.F.R.A., Dominion Experimental Farms (now with Division of Soils, University of Minnesota).

Salisbury and DeLong (11) in studying virgin and cultivated soils found only small losses of organic matter as a result of cultivation.

In the first report on this investigation (3) the total organic carbon and nitrogen analyses of cultivated and virgin samples from 34 widely scattered points in Alberta and Saskatchewan were published, and it was shown that on the average fairly large losses of these two constituents had occurred under cultivation.

More recent work on this problem has been extended to include Manitoba and the Peace River district of Alberta. Samples have also been collected from more recently broken fields and adjacent uncultivated soil in order to obtain estimations of the rates of loss, and to determine whether the rate of loss is most rapid after the land is first broken. A preliminary outline of some of the more recent work on this project was published as Part II of this series (2).

In this paper some of the data showing effects of cultivation and cropping on chemical composition of soils, published in the first report of this investigation (3) are repeated for purposes of direct comparison with previously unpublished data. This has been done in many cases in order to compare effects of a relatively short period of cultivation with the previously reported effects of cultivation for many years, in the same district or location.

While obvious erosion, both by wind and water, plays a great part in soil depletion, it is outside the scope of this investigation. This particular project has been chiefly concerned with losses from cultivated soil due to decomposition of organic matter together with volatilization and leaching, and removal of essential plant nutrients by crops. However, it is quite likely that erosion often plays a part in soil deterioration under cultivation even when the effects are not readily observable.

Soil Samples

METHODS

Up to the present, samples from 85 locations, representing 85 comparisons of virgin and cultivated soil, have been collected from various points in Alberta, Saskatchewan and Manitoba. The investigation has involved the chemical analysis of more than 1000 composite or individual samples of soil.

Duplicate samples of relatively old cultivated and nearby virgin soil were obtained at each location. Also in 22 cases similar samples of more recently broken fields and corresponding virgin soil were obtained at or near the same location in order to study rates of loss. Duplicate composite samples of surface soil were obtained in all cases, and in most cases composite samples of the second or 6- to 12-inch depth were obtained also. Each composite was made up of a mixture of 10 or more well mixed replicate samples taken at random within the sampled area. The adjacent areas of cultivated and uncultivated soil from which composite samples were taken each consisted of not more than 1/10 acre as a rule, and were usually separated by a fence or roadway. For the most part the samples obtained were taken in the field according to profile, but in some cases the surface horizon was divided, and in others two and even part of a third horizon were combined to make up the ploughing depth. The average plough depth was taken as 6 to 7 inches.

Samples of the subsoil (below the depth of 12 inches) were obtained, but it was considered better not to include the subsoil composition in the tables which show the effects of cultivation, since the composition of the subsoil would probably not be affected by cultivation nearly as much as the composition of the surface soil. Moreover, since composite samples of subsoil were not obtained as a rule, the composition of the single samples obtained would be less representative, and, if included, would tend to increase the error or obscure the effects of cultivation. However, the subsoil samples were analysed for total organic carbon and nitrogen, and, in some cases, other elements. These analyses will be published later in order to indicate the character of the subsoil.

An attempt was made to sample cultivated and adjacent uncultivated soils that were uniform in texture and profile, and free from erosion or drifting. It is probably impossible to avoid erosion or drifting entirely, but the appearance of the profile and surrounding soil will usually show whether this has been appreciable.

Something of the history of the field was always obtained, such as length of time cultivated, types of crops grown, rotations used, fertilizers and manures applied, if any. Usually, fertilized fields were avoided since this would complicate the particular problem.

The samples were taken to the laboratory, where the larger stones and heavier debris were removed. They were then air-dried, well mixed, and a portion of each sample was finely ground in a Braun pulverizer for chemical analyses.

All samples were analysed for organic carbon and total nitrogen. The results of these analyses are given in this paper and in previously published papers (2, 3). Carbon to nitrogen ratios have been calculated from the percentages of organic carbon and total nitrogen.

Many of the samples have been analysed for total phosphorus, easily soluble phosphorus, water-soluble phosphorus, total sulphur, and pH values. Nitrification studies and carbon dioxide evolution studies have also been carried out with some of the surface samples. These results will be published in subsequent papers.

Organic Carbon

Organic carbon was determined by Schollenberger's chromic acid reduction method as modified by Allison (1). Organic matter was calculated by multiplying organic carbon by the factor 1.724.

Total Nitrogen

The total nitrogen was determined by the Kjeldahl-Gunning-Hibbard method, modified by the addition of selenium as a catalyst (9).

RESULTS

Total Organic Carbon, Organic Matter, and Nitrogen

All samples of soil were analysed for total organic carbon in order to determine their organic matter content. The organic carbon contents of the upper 6 inches and of the subsurface 6 to 12 inches, and the organic matter content of the upper 12 inches of soil, in the different soil zones, are

shown in Tables 1 to 6. The averages of the different soil zones are shown in Table 7 for convenient comparison of the organic carbon and organic matter of the soils of the different zones.

TABLE 1.—LOSS OR GAIN OF ORGANIC CARBON IN CULTIVATED BROWN SOILS

Location	Surface soil class	Years cult.	0"-6"			6"-12"			0"-12"	
			Orig. %	Loss or gain		Orig. %	Loss or gain		Loss or gain Lb./acre	
				% of orig.	Lb./acre		% of orig.	Lb./acre	Organic carbon	Organic matter
Brooks	L.	12	2.18	-42	-16,470	1.50	-3	-8,010	-24,480	-42,228
Brooks	L.	3	3.63	-11	-8,000	1.06	+8	+1,700	-6,300	-10,868
Cabri	C.	26	1.27	-2	-4,590	0.99	-8	-1,440	-6,030	-10,402
Cabri	C.	13	1.39	-10	-2,800	0.95	-1	-100	-2,900	-5,003
Cavendish	F.S.L.	23	1.78	-28	-9,060	1.09	-4	-810	-9,870	-17,026
Cavendish	F.S.L.	11	1.74	-4	-1,300	0.81	+15	+2,500	+1,200	+2,070
Gros Ventre	L.	20	4.06	-43	-31,320	1.24	-28	-6,300	-37,620	-64,895
Gros Ventre	L.	9	3.81	-51	-38,500	0.96	-7	-1,400	-39,900	-68,828
Swift Current	L.	15	3.42	+2	+1,260	1.31	-21	-5,940	-4,680	-8,073
Swift Current	L.	30	5.35	-38	-36,990	1.27	+2	+360	-36,630	-63,187
Swift Current	L.	14	3.53	-2	-1,500	2.12	-28	-11,700	-13,200	-22,770
Average of 11 locations		16	2.92	-21	-13,570	1.21	-7	-2,831	-16,401	-28,292
Average of all samples (13 locations)		—	—	-22	-11,943	—	-13	-2,878	-14,821	-25,566

TABLE 2.—LOSS OR GAIN OF ORGANIC CARBON IN CULTIVATED DARK BROWN SOILS

Location	Surface soil class	Years cult.	0"-6"			6"-12"			0"-12"	
			Orig. %	Loss or gain		Orig. %	Loss or gain		Loss or gain Lb./acre	
				% of orig.	Lb./acre		% of orig.	Lb./acre	Organic carbon	Organic matter
Cutknife	L.	31	4.50	-32	-26,010	1.59	-25	-6,600	-32,610	-56,252
Cutknife	L.	4	4.35	+2	+1,700	1.65	+10	+3,400	+5,100	+8,798
Edgerton	L.	26	4.21	-19	-14,220	2.26	-16	-5,370	-19,590	-33,793
Edgerton	L.	12	5.50	-25	-27,300	2.23	-6	-2,800	-30,100	-51,923
Estevan	L.	33	4.54	-49	-44,200	1.19	-43	-10,200	-54,400	-93,840
Hand Hills	L.	20	3.01	-3	-1,700	1.93	-11	-4,000	-5,700	-9,833
Hand Hills	L.	9	4.72	-32	-30,100	1.23	+13	+3,300	-26,800	-46,230
Hanley	L.	30	2.22	-12	-5,500	1.04	-11	-2,200	-7,700	-13,283
Hanley	L.	6	4.48	+4	+3,400	1.94	-8	-3,100	+300	+518
Lethbridge										
Rotation U	L.	25*	2.52	-14	-6,679	1.65	-2	-141	-6,820	-11,765
Lethbridge										
Rotation C	L.	26*	2.56	-39	-18,000	1.18	0	+180	-17,820	-30,740
Lethbridge	L.	8	2.53	+2	+800	1.20	+26	+6,100	+6,900	+11,903
Morrin	C.	26	4.90	-30	-20,370	2.17	-4	-1,710	-28,080	-48,438
Morrin	C.	13	3.60	-14	-10,400	2.20	-22	-9,500	-19,900	-34,328
Regina E.	L.	49	4.32	-40	-31,400	1.09	-21	-4,140	-35,540	-61,307
Regina E.	L.	15	5.01	-28	-27,600	1.81	-25	-9,000	-36,600	-63,135
Regina S.	C.	50	3.37	-49	-29,790	1.52	-1	-360	-30,150	-52,009
Regina N.	C.	5	4.60	-13	-11,500	2.08	+11	+4,500	-7,000	-12,075
Waskada	L.	30	5.21	-28	-29,400	2.89	+4	+2,100	-27,300	-47,093
Average of 19 locations		22	4.01	-22	-17,593	1.73	-7	-2,081	-19,674	-33,938
Average of all samples (20 locations)		—	—	-21	-16,209	—	-8	-2,509	-18,718	-32,289

* Years under this rotation.

TABLE 3.—LOSS OR GAIN OF ORGANIC CARBON IN CULTIVATED BLACK SOILS

Location	Surface soil class	Years cult.	0''-6''			6''-12''			0''-12''	
			Orig. %	Loss or gain		Orig. %	Loss or gain		Loss or gain Lb./acre	
				% of orig.	Lb./acre		% of orig.	Lb./acre	Organic carbon	Organic matter
Brandon	F.S.L.	50 +	5.86	-34	-39,600	2.65	-19	- 9,900	-49,500	-85,388
Indian Head										
Rot. R.	C.L.	29*	3.03	-26	-15,900	2.48	-15	- 7,300	-23,200	-40,020
Indian Head										
Rot. C.	C.L.	29*	3.53	-29	-20,800	3.57	-42	-30,300	-51,100	-88,148
Lacombe Rot. C.	C.L.	25*	7.39	- 8	-11,160	6.86	-21	-25,380	-36,540	-63,032
Lacombe Rot. O.	O.L.	26*	5.13	+ 3	+ 2,600	3.23	+13	+ 7,900	+10,500	+18,113
Lloydminster	L.	5	7.29	-10	-15,000	2.93	-25	-14,800	-29,800	-51,405
Lloydminster	L.	32	6.79	-25	-34,400	2.14	+21	+ 9,200	-25,200	-43,470
Melfort	L.	30	8.36	-16	-24,120	4.77	+12	+ 9,930	-14,190	-24,478
Melfort	L.	4	7.76	-27	-43,200	2.74	-26	-14,000	-57,200	-98,670
Parkland	L.	27	5.86	-43	-45,540	2.38	-23	- 9,810	-55,350	-95,479
Parkland	L.	10	4.21	- 8	- 7,000	1.58	- 3	- 1,100	-8,100	-13,973
Pincher Creek	Si. L.	27	7.97	-38	-53,820	2.39	-13	- 9,120	-62,940	-108,572
Pincher Creek	Si. L.	13	7.03	-44	-62,300	3.45	-42	-28,700	-91,000	-156,975
Portage la										
Prairie	Si. L.	50 +	5.38	-20	-21,100	3.34	-16	-10,900	-32,000	-55,200
Selkirk	C.L.	24	8.96	-30	-53,300	4.85	-27	-25,900	-79,200	-136,620
Vegreville	L.	30	6.94	-17	-23,982	2.91	-13	- 7,754	-31,736	-54,745
Vegreville	L.	9	6.94	-14	-19,432	2.93	0	-100	-19,532	-33,673
Winkler	L.	50 +	3.20	+14	+ 8,700	4.16	-17	-14,400	-5,700	- 9,833
Yorkton	L.	40	5.80	-22	-25,000	2.71	-12	- 6,400	-31,400	-54,165
Yorkton	L.	10	5.96	- 6	- 7,600	3.73	-32	-23,600	-31,200	-53,820
Average of 20 locations		26	6.09	-18	-25,598	3.16	-11	-10,622	-36,220	-62,443
Average of all samples (22 locations)		—	—	-19	-27,526	—	-10	- 8,979	-36,505	-62,935

Years under this rotation.

TABLE 4.—LOSS OR GAIN OF ORGANIC CARBON IN CULTIVATED BLACK-TRANSITION SOILS

Location	Surface soil class	Years cult.	0''-6''			6''-12''			0''-12''	
			Orig. %	Loss or gain		Orig. %	Loss or gain		Loss or gain Lb./acre	
				% of orig.	Lb./acre		% of orig.	Lb./acre	Organic carbon	Organic matter
Fairview	Si. L.	11	8.63	-34	-59,200	2.05	-26	-10,500	-69,700	-120,233
Fairview	Si. L.	28	9.10	-34	-62,700	2.91	-31	-18,100	-80,800	-139,380
Beaverlodge	C.L.	21	7.32	-10	-14,400	1.55	-12	- 3,800	-18,200	- 31,395
Grande Prairie	L.	25	4.09	-12	-10,100	1.25	-10	- 2,600	-12,700	- 21,908
High Prairie	C.L.	11	11.43	-22	-51,300	3.41	-25	-17,000	-68,300	-117,818
High Prairie	C.L.	29	11.36	-45	-103,100	2.27	-13	- 6,000	-109,100	-188,198
Dauphin	C.L.	45	7.32	-12	-17,400	5.12	+ 2	+ 2,400	- 15,000	- 25,875
Average of 7 locations		24	8.46	-24	-45,457	2.65	-16	- 7,943	- 53,400	- 92,115
Average of all samples (7 locations)		—	—	-24	-45,457	—	-16	- 7,943	- 53,400	- 92,115

TABLE 5.—LOSS OR GAIN OF ORGANIC CARBON IN CULTIVATED GRAY-TRANSITION SOILS

Location	Surface soil class	Years cult.	0"-6"			6"-12"			0"-12"	
			Orig. %	Loss or gain		Orig. %	Loss or gain		Loss or gain Lb./acre	
				% of orig.	Lb./acre		% of orig.	Lb./acre	Organic carbon	Organic matter
Debolt	C.L.	20	2.65	+ 6	+ 3,400	0.83	+12	+2,000	+5,400	+ 9,315
Debolt	C.L.	5	2.65	+26	+13,700	0.83	- 8	-1,300	+12,400	+21,390
Nampa	H.C.L.	19	7.25	-36	-52,800	1.29	- 1	-200	-53,000	-91,425
Nampa	H.C.L.	5	7.25	-43	-61,800	1.29	+20	+5,100	-56,700	-97,808
Average of 4 locations		12	4.95	-12	-24,375	1.06	+ 6	+1,400	-22,975	-39,632
Average of all samples (4 locations)		—	—	-12	-24,375	—	+ 6	+1,400	-22,975	-39,632

TABLE 6.—LOSS OR GAIN OF ORGANIC CARBON IN CULTIVATED GRAY SOILS

Location	Surface soil class	Years cult.	0"-6"			6"-12"			0"-12"	
			Orig. %	Loss or gain		Orig. %	Loss or gain		Loss or gain Lb./acre	
				% of orig.	Lb./acre		% of orig.	Lb./acre	Organic carbon	Organic matter
Breton C-1	Si. L.	14	2.69	-51	-24,750	0.81	-33	-4,875	-29,625	-51,103
Breton C-3*	Si. L.	14	2.69	-49	-23,580	0.81	-35	-4,980	-28,560	-49,266
Breton E-1	Si. L.	14	2.75	-49	-27,100	0.88	-23	-4,100	-31,200	-53,820
Breton E-3*	Si. L.	14	2.75	-48	-26,100	0.88	-27	-4,700	-30,800	-53,130
Breton	Si. L.	15	2.19	-17	- 7,300	0.69	- 4	-500	- 7,800	-13,455
Carrot Creek	Si. L.	5	2.05	- 4	- 1,700	0.70	- 1	-200	- 1,900	- 3,278
Cherhill	Si. L.	11	2.13	-18	- 7,800	0.77	- 5	-800	- 8,600	-14,835
Edson	Si. L.	24	1.32	-36	- 9,500	0.57	- 8	-900	-10,400	-17,940
Goodfare	Si. L.	21	2.63	-37	-19,600	1.33	-29	-7,700	-27,300	-47,093
Gunn	L.	11	3.19	-18	-11,200	0.90	-13	-2,300	-13,500	-23,288
Love	Si. L.	7	2.62	-36	-18,600	0.86	-30	-1,200	-19,800	-34,155
Mackay	Si. L.	3	1.81	-10	- 3,240	0.66	+ 6	+735	- 2,505	- 4,321
Mackay	Si. L.	14	2.74	+16	+ 8,900	0.83	-10	+1,600	+10,500	+18,113
Average of 13 locations		13	2.43	-27	-13,198	0.82	-16	-2,302	-15,499	-26,736
Average of all samples (19 locations)		—	—	-29	-13,850	—	-18	-2,538	-16,388	-28,253

* Complete fertilizer applied annually for last 9 years.

When all previously published analyses are included the average loss figures are changed as shown in the tables, but only to a small extent.

Only a relatively small number of samples was obtained from locations within the black-transition and gray-transition soil zones (or sub-zones), and consequently the averages obtained from the analyses of these samples are less representative than those of the other soil zones. Moreover, the soils within the transition zones are frequently quite variable in composition. Those of the black-transition zone usually possess many of the charac-

TABLE 7.—AVERAGE LOSSES OF ORGANIC CARBON AND ORGANIC MATTER FROM CULTIVATED SOILS OF DIFFERENT SOIL ZONES

Soil zone	No. locations sampled	Av. no. years cult.	0''-6''			6''-12''			0''-12''	
			Organic carbon			Organic carbon			Av. loss	
			Av. loss			Av. loss			Lb./acre	
			Orig. %	% of orig.	Lb. per acre	Orig. %	% of orig.	Lb. per acre	Organic carbon	Organic matter
Brown	11	16	2.92	21	13,570	1.21	7	2,831	16,401	28,292
Brown	13	—	—	22	11,943	—	13	2,878	14,821	25,566
Dark brown	19	22	4.01	22	17,593	1.73	7	2,081	19,674	33,938
Dark brown	20	—	—	21	16,209	—	8	2,509	18,718	32,289
Black	20	26	6.09	18	25,598	3.16	11	10,622	36,220	62,443
Black	22	—	—	19	27,526	—	10	8,979	36,505	62,935
Black-transition	7	24	8.46	24	45,457	2.65	16	7,943	53,400	92,115
Gray-transition	4	12	4.95	12	24,375	1.06	6	1,400	22,975	39,632
Gray	13	13	2.43	27	13,198	0.82	16	2,302	15,499	26,736
Gray	19	—	—	29	13,850	—	18	2,538	16,388	28,253

teristics of the black soil zone and those of the gray-transition zone many of the characteristics of the gray soil zone. Most of the black-transition soils sampled were exceptionally rich in organic matter.

A statistical analysis of the data has shown that the average losses of organic carbon or organic matter from the surface 6 inches of the brown, dark brown, black (including black-transition), gray (including gray-transition) and gray soils, are significant in all cases, and that the losses from the subsurface, or 6- to 12-inch depth are significant in all cases also (Table 8).

TABLE 8.—SIGNIFICANCE OF LOSSES OF CARBON FROM CULTIVATED SOILS OF DIFFERENT SOIL ZONES (SURFACE AND SUBSURFACE LAYERS)

Soil zone	Depth	No. cult. fields or locations	Av. no. years cult.	Av. total loss	Min. sig. loss*
Brown	0''- 6''	11	18.7	% 0.65	% 0.50
Brown	6''-12''	10	18.4	0.14	0.14
Dark brown	0''- 6''	19	21.4	0.90	0.35
Dark brown	6''-12''	18	22.2	0.13	0.11
Black (including black-transition)	0''- 6''	31	24.8	1.39	0.45
Black (including black-transition)	6''-12''	30	25.5	0.55	0.34
Gray (including gray-transition)	0''- 6''	19	14.3	0.73	0.44
Gray (including gray-transition)	6''-12''	18	14.9	0.13	0.10
Gray	0''- 6''	13	13.5	0.49	0.31
Gray	6''-12''	12	14.3	0.14	0.08

*At 5% level of significance.

TABLE 9.—LOSS OR GAIN OF NITROGEN IN CULTIVATED BROWN SOILS

Location	Surface soil class	Years cult.	Orig. %	0''-6''		Orig. %	6''-12''		0''-12''
				Loss or gain			Loss or gain		Loss or gain Lb./acre
				% of orig.	Lb./acre		% of orig.	Lb./acre	
Brooks	L.	12	.159	-32	-1044	.111	-18	-414	-1458
Brooks North	L.	3	.294	-7	-440	.113	+14	+310	-130
Cavendish	F.S.L.	23	.143	-18	-441	.099	+13	+234	-207
Cavendish	L.	11	.153	+4	+130	.077	+37	+570	+700
Gros Ventre	L.	20	.291	-36	-1890	.111	-29	-594	-2484
Gros Ventre	L.	9	.292	-43	-2510	.090	-1	-10	-2520
Cabri	C.	26	.134	-21	-162	.106	-6	-42	-204
Cabri	C.	13	.155	-3	-80	.117	+5	+120	+40
Swift Current	L.	30	.394	-33	-2340	.104	+9	+171	-2169
Swift Current	L.	14	.308	-6	-340	.200	-30	-1200	-1540
Swift Current	L.	15	.266	+2	+90	.114	-24	-378	-288
Average of 11 locations		16	.235	-18	-820	.113	-3	-112	-933
Average of all samples (13 locations)		—	—	-17	-779	—	-5	-110	-889

TABLE 10.—LOSS OR GAIN OF NITROGEN IN CULTIVATED DARK BROWN SOILS

Location	Surface soil class	Years cult.	Orig. %	0"-6"		Orig. %	6"-12"		0"-12"
				Loss or gain			Loss or gain		Loss or gain Lb./acre
				% of orig.	Lb./acre		% of orig.	Lb./acre	
Lethbridge Rotation C	Si. L.	26*	.206	-37	-1368	.102	+12	+126	-1242
Lethbridge Lethbridge Rotation U	Si. L.	8	.217	+ 6	+ 270	.122	+25	+610	+ 880
Morrin	C.	26	.413	-21	-1750	.213	+ 3	+120	-1630
Morrin	C.	13	.327	- 8	- 550	.230	-15	-710	-1260
Hand Hills	L.	20	.221	+ 1	- 168	.144	- 7	+122	- 46
Hand Hills	L.	9	.351	-27	-1890	.126	+ 8	+200	-1690
Edgerton	L.	26	.336	- 9	- 540	.193	- 6	- 42	- 582
Edgerton	L.	12	.421	-22	-1880	.179	+ 1	+ 30	-1850
Cutknife	L.	31	.336	-28	-1692	.121	-23	-492	-2184
Cutknife	L.	4	.342	+ 6	+ 410	.147	+10	+280	+ 690
Hanley	L.	30	.194	- 7	- 290	.099	- 7	-140	- 430
Hanley	L.	6	.369	+ 4	+ 300	.176	- 5	-190	+ 110
Regina South	C.	50	.313	-43	-2412	.164	- 5	-162	-2574
Regina North	C.	5	.402	- 7	- 580	.221	+ 7	+330	- 250
Regina East	L.	49	.327	-39	-2286	.088	-13	-198	-2484
Regina East	L.	15	.417	-25	-2080	.174	-14	-500	-2580
Estevan	L.	33	.371	-42	-3150	.115	-25	-590	-3740
Waskada	L.	30	.428	-24	-2030	.254	+ 7	+370	-1660
Average of 19 locations		—	.326	-17	-1156	.159	- 2	- 41	-1197
Average of all samples (20 locations)		—	—	-18	-1173	—	- 1	- 35	-1208

*Years under this rotation.

The black and black-transition soils have lost most organic matter whereas the brown and gray soils have lost the least (Table 7). Thus it will be observed that the losses increase with increase in original organic matter content.

Both total losses and percentage of original organic carbon content losses from the subsurface or 6- to 12-inch depth were small on the average as compared to the losses from the upper 6-inch depth (Table 7).

The losses in percentage of original organic carbon content from the surface 6 inches of brown, dark brown, and black soils were much alike on the average, and amounted to about 20% of the original content (Table 7).

The losses in percentage of original organic carbon content from the surface 6 inches were greatest in the case of the gray soils, amounting on the average to about 29% of the original content (Table 7).

All samples of soil were analysed for total nitrogen. The total nitrogen contents of the upper 6 inches, the subsurface 6 to 12 inches, and the upper 12 inches of soil in the different soil zones are shown in Tables 9 to 14. The averages of the different soil zones are shown in Table 15 for convenient comparison of the total nitrogen contents of the soils of the different zones.

TABLE 11.—LOSS OR GAIN OF NITROGEN IN CULTIVATED BLACK SOILS

Location	Surface soil class	Years cult.	Orig. %	0''-6''		Orig. %	6''-12''		0''-12''
				Loss or gain			Loss or gain		Loss or gain Lb./acre
				% of orig.	Lb./acre		% of orig.	Lb./acre	
Pincher Creek	Si. L.	27	.577	-20	-3222	.242	-21	-507	-3729
Pincher Creek	Si. L.	13	.554	-41	-4560	.289	-33	-1910	-6470
Parkland	L.	27	.440	-41	-3250	.151	+ 6	+ 170	-3080
Parkland	L.	10	.344	- 5	- 330	.143	- 2	- 60	- 390
Lacombe, Rotation C	L.	25*	.552	- 3	- 270	.413	- 1	-100	- 370
Lacombe, Rotation O	L.	26*	.412	+ 7	+ 560	.276	- 1	- 80	+ 480
Vegreville	L.	30	.506	-16	-1582	.151	-15	- 443	-2025
Vegreville	L.	9	.506	- 8	- 860	.219	+ 8	+360	- 500
Lloydminster	L.	31	.549	-27	-3000	.297	-45	-2760	-5760
Lloydminster	L.	5	.592	- 6	- 760	.256	-22	-1130	-1890
Melfort	L.	30	.646	-16	-1818	.374	+18	+1242	- 576
Melfort	C.L.	4	.614	-25	-3060	.235	-23	-1060	-4120
Yorkton	L.	40	.512	-24	-2500	.242	- 8	- 380	-2880
Yorkton	L.	10	.514	- 6	- 570	.341	-29	-1970	-2540
Indian Head, Rotation R	C.L.	29*	.279	-20	-1100	.240	-14	- 650	-1750
Indian Head, Rotation C	C.L.	29*	.314	-28	-1770	.312	-38	-2360	-4130
Brandon	F.S.L.	50	.456	-33	-2980	.219	-17	- 760	-3740
Portage la Prairie	Si. L.	50	.427	-15	-1280	.272	-13	- 720	-2000
Winkler	C.L.	50	.266	+ 8	+ 450	.334	-18	-1210	- 760
Selkirk	C.L.	24	.709	-27	-3880	.400	-24	-1890	-5770
Average of 20 locations		26	.487	-17	-1789	.270	-15	- 811	-2600
Average of all samples (22 locations)		—	—	-18	-1891	—	-15	- 767	-2658

* Years under this rotation.

TABLE 12.—LOSS OR GAIN OF NITROGEN IN CULTIVATED BLACK-TRANSITION SOILS

Location	Surface soil class	Years cult.	Orig. %	0''-6''		Orig. %	6''-12''		0''-12''
				Loss or gain			Loss or gain		Loss or gain Lb./acre
				% of orig.	Lb. /acre		% of orig.	Lb./acre	
Fairview	Si. L.	11	.797	-34	-5380	.192	-15	-580	-5960
Fairview	Si. L.	28	.797	-33	-5210	.277	-28	-1560	-6770
Beaverlodge	C.L.	21	.697	-7	-1000	.146	-3	-80	-1080
Grande Prairie	Si. L.	25	.361	-1	-80	.138	-5	-140	-220
High Prairie	C.L.	29	.843	-43	-7280	.177	-9	-310	-7590
High Prairie	C.L.	11	.857	-12	-2170	—	—	—	—
Dauphin	C.L.	45	.644	-7	-900	.456	+6	+550	-350
Average of 7 locations		24	.714	-20	-3146	.231	-9	-353	-3662
Average of all samples (7 locations)		—	—	-20	-3146	—	-9	-353	-3662

TABLE 13.—LOSS OR GAIN OF NITROGEN IN CULTIVATED GRAY-TRANSITION SOILS

Location	Surface soil class	Years cult.	Orig. %	0''-6''		Orig. %	6''-12''		0''-12''
				Loss or gain			Loss or gain		Loss or gain Lb./acre
				% of orig.	Lb./acre		% of orig.	Lb./acre	
Nampa	C.L.	19	.602	-32	-3870	.161	+ 8	+260	-3610
Nampa	C.L.	5	.602	-28	-3380	.161	+18	+590	-2790
Debolt	H.C.L.	20	.278	-64	-3530	.099	+ 4	+ 70	-3460
Debolt	H.C.L.	5	.278	+ 1	+ 80	.099	- 2	- 40	+ 40
Average of 4 locations		—	.440	-31	-2675	.130	+ 7	+220	-2455
Average of all samples (4 locations)		—	—	-31	-2675	—	+ 7	+220	-2455

TABLE 14.—LOSS OR GAIN OF NITROGEN IN CULTIVATED GRAY SOILS

Location	Surface soil class	Years cult	Orig. %	0''-6''		Orig. %	6''-12''		0''-12''
				Loss or gain			Loss or gain		Loss or gain Lb./acre
				% of orig.	Lb./acre		% of orig.	Lb./acre	
Breton C-1	Si. L.	14	.148	-43	-1152	.052	-34	-312	-1464
Breton C-3*	Si. L.	14	.148	-41	-1098	.052	-20	-273	-1371
Breton E-1	Si. L.	14	.151	-30	-910	.064	-11	-140	-1050
Breton E-3*	Si. L.	14	.151	-31	-950	.064	-14	-180	-1130
Breton	Si. L.	15	.113	-3	-60	.053	+5	+50	-10
Gunn	L.	11	.358	-57	-4060	.052	+18	+190	-3870
Cherhill	Si. L.	11	.219	-45	-1950	.051	+33	+340	-1610
Mackay	Si. L.	3	.072	-35	-450	—	—	—	—
Mackay	Si. L.	14	.193	-2	-60	.071	+1	+20	-40
Carrot Creek	Si. L.	5	.284	-59	-3330	.066	-5	-70	-3400
Edson	Si. L.	24	.111	-40	-890	.054	-3	-30	-920
Goodfare	Si. L.	21	.190	-27	-1010	.080	+24	+390	-620
Love	Si. L.	7	.338	-68	-4610	.059	-3	-30	-4640
Average of 13 locations		13	.190	-37	-1579	.060	-1	-4	-1583
Average of all samples (19 locations)		—	—	-31	-1257	—	-4	-51	-1308

* Complete fertilizer applied annually for last 9 years.

TABLE 15.—AVERAGE LOSSES OF NITROGEN FROM CULTIVATED SOILS OF DIFFERENT SOIL ZONES

Soil zone	No. locations sampled	Av. no. years cult.	0''-6''			6''-12''			0''-12''
			Nitrogen orig. %	Av. loss		Nitrogen orig. %	Av. loss		Av. loss, lb. per acre
				% of orig.	lb. per acre		% of orig.	Lb. per acre	
Brown	11	16	.235	18	820	.113	3	112	933
Brown	13	—	—	17	779	—	5	110	889
Dark brown	19	22	.326	17	1156	.159	2	41	1197
Dark brown	20	—	—	18	1173	—	1	35	1208
Black	20	26	.487	17	1789	.270	15	811	2600
Black	22	—	—	18	1891	—	15	767	2658
Black-transition	7	24	.714	20	3146	.231	9	353	3662
Gray-transition	4	12	.440	31	2675	.130	+7	+220	2455
Gray	13	13	.190	37	1579	.060	1	4	1583
Gray	19	—	—	31	1257	—	4	51	1308

TABLE 16.—SIGNIFICANCE OF LOSSES OF NITROGEN FROM CULTIVATED SOILS OF DIFFERENT SOIL ZONES (SURFACE AND SUBSURFACE LAYERS)

Soil zone	Depth	No. cult. fields or locations	Av. no. years cult.	Av. total loss	Min. sig. loss*
				%	%
Brown	0'-6''	11	18.7	.040	.033
Brown	6'-12''	10	18.4	.012	.015
Dark brown	0'-6''	19	21.4	.060	.021
Dark brown	6'-12''	19	21.4	.003	.007
Black (including black-transition)	0'-6''	31	24.8	.097	.035
Black (including black-transition)	6'-12''	30	25.5	.039	.027
Gray (including gray-transition)	0'-6''	19	14.3	.038	.026
Gray (including gray-transition)	6'-12''	18	14.9	.005	.007
Gray	0'-6''	13	13.5	.030	.011
Gray	6'-12''	12	14.3	.007	.005

* At 5% level of significance.

When all previously published analyses are included the average loss figures are changed as shown in the tables, but only to a small extent.

As stated previously in connection with the organic carbon results, relatively few samples were obtained from locations within the black-transition and gray-transition soil zones (or sub zones), and consequently the averages obtained from the analyses of these samples are less representative than those of the other soil zones. Moreover, the soils within

the transition zones are frequently quite variable in composition. Most of the black-transition soils sampled were exceptionally rich in nitrogen and organic matter.

A statistical analysis of the data has shown that the average losses of nitrogen from the surface 6 inches of the brown, dark brown, black (including black-transition), gray (including gray-transition) and gray soils, are significant in all cases, and that the losses from the subsurface or 6- to 12-inch depth are significant only in the cases of the black (including black transition) and gray soils (Table 16).

The black and black-transition soils have on the average lost the most nitrogen as well as the most organic matter, whereas the brown and gray soils have lost the least (Table 15). Thus it will be observed that the losses of both nitrogen and organic matter increased with increase in original nitrogen and organic matter content.

Both total losses and percentage of original nitrogen content losses from the subsurface or 6- to 12-inch depth were small on the average as compared to the losses from the upper 6-inch depth (Table 15). This was also true of the organic carbon losses. Both total and percentage of original nitrogen content losses from the 6- to 12-inch depth were greatest in the case of the black soils. This may be due to the fact that the surface organic matter layer is relatively deep in the black soils.

The losses in percentage of original nitrogen content from the surface 6 inches of brown, dark brown, black and black-transition soils were much alike on the average, varying from 17 to 20% (Table 15).

The average losses in percentage of original nitrogen content were 31 and 31% respectively in the cases of the gray and gray-transition soils. These losses were considerably greater than in the cases of the other soil zones.

A grain and fallow system of dry land farming is followed on the Rotation C dark brown soil plots at Lethbridge. This 3-year rotation, consisting of wheat, wheat, and fallow had been followed for 26 years when soil samples were obtained for the analyses shown in Tables 2 and 10.

Rotation U at Lethbridge is a 10-year rotation consisting of 6 years of alfalfa, followed by sugar beets (or another hoed crop), wheat, oats, and barley. This rotation had been followed on irrigated land for 25 years when soil samples were obtained for the analyses shown in Tables 2 and 10. Farm manure had been applied only once every 10 years at the rate of 12 tons per acre.

It will be observed that the losses of organic carbon were small and that the losses of nitrogen were very small in the alfalfa rotation plot soils as compared to the losses from the wheat and fallow rotation plots, and as compared to the average losses at all locations in the dark brown soil zone.

Rotation C, a 3-year grain and fallow rotation consisting of wheat, wheat, and fallow, had been followed on the black soil at Lacombe for 25 years before samples of soil were obtained for the analyses reported in Tables 3 and 11.

Rotation O, at Lacombe, is a 7-year rotation consisting of wheat, oats, fallow, wheat (seeded to alfalfa and rye grass), hay (manured), hay (broken early), and potatoes. This rotation had been followed for 26 years when samples were obtained for the analyses reported in Tables 3 and 11.

The analyses indicate that there was a large loss of organic carbon and some loss of nitrogen from the wheat and fallow rotation plots at Lacombe, whereas there were small gains of organic carbon and nitrogen in the plots under a rotation which includes a legume, grass and manure.

Rotation C at Indian Head is a 3-year, wheat, wheat and fallow rotation (as at Lacombe and Lethbridge). This rotation had been followed on the black soil at Indian Head for 29 years before samples of soil were obtained for the analyses reported in Tables 3 and 11.

Rotation R at Indian Head is a 9-year rotation consisting of wheat, oats, fallow, wheat, oats (seeded down to grass and alfalfa), hay, hay or pasture, pasture (broken), and corn (manured). This rotation had been followed for 29 years when samples were obtained for the analyses reported in Tables 3 and 11.

The analyses indicate that there were large losses of organic carbon and nitrogen from the wheat and fallow rotation plot soil at Indian Head, and losses also, but much smaller losses from this soil under a rotation which includes a mixture of grass and alfalfa, and an application of farm manure.

A grain and fallow system of farming was followed on the gray wooded soil Breton E1 and E3 plots for 14 years before samples were obtained for analysis, as shown in Tables 6 and 14. During this period plot E1 received no fertilizer, whereas plot E3 received 8 annual applications of complete fertilizer at the rate of approximately 100 lb. per acre per year. The analyses indicate that the losses of carbon and nitrogen from these two plots were about equal. The losses of organic carbon were above the average of the gray soils and the losses of nitrogen rather less than average.

A 4-year rotation of crops consisting of wheat, oats, barley (seeded to clover), and clover, was followed on the Breton C1 and C3 plots for 8 years before samples were obtained for analysis as shown in Tables 6 and 14. During this period plot C1 received no fertilizer, whereas plot C3 received 8 annual applications of complete fertilizer at the rate of about 100 pounds per acre per year. The analyses indicate that the losses of organic carbon and nitrogen from these two plots were much alike. The losses of organic carbon were greater than the average loss from the gray soils and the losses of nitrogen about average.

Comparative Rates of Loss of Organic Carbon and Nitrogen from Newer and Older Cultivated Fields

This investigation of soil deterioration includes the determination of losses of several soil constituents from more recently broken fields, as well as from older cultivated fields. Samples of newer and older cultivated fields together with corresponding virgin soils were obtained at 22 locations. The samples were taken close together at each location and represented similar soils. The losses or gains of the individual fields are given in Tables 1 to 6 and 9 to 14. The object was to obtain some estimations of the rates of losses, and, more particularly, to find out if the rate of loss is most rapid during the first few years after the virgin land is broken.

The average annual loss of organic carbon from the older cultivated fields (cultivated on the average for 28.5 years) was approximately half that of the newer cultivated fields (cultivated on the average for 9.2 years), and the average annual loss of nitrogen from the older cultivated fields was less than two-thirds that of the newer fields. (Table 17).

TABLE 17.—COMPARATIVE RATES OF LOSS OF ORGANIC CARBON AND NITROGEN FROM NEWER AND OLDER CULTIVATED FIELDS

—	Depth	No. cult. fields or locations	Av. no. years cult.	Av. ann. loss	Av. total loss	Min. sig. loss*
				%	%	%
ORGANIC CARBON						
Newer cultivated fields	0''–6''	22	9.2	0.107	0.98	0.51
Older cultivated fields	0''–6''	22	28.5	0.052	1.49	0.49
NITROGEN						
Newer cultivated fields	0''–6''	22	9.2	.0062	.057	.033
Older cultivated fields	0''–6''	22	28.5	.0038	.108	.041

* At 5% level of significance.

Carbon to Nitrogen Ratios of Virgin and Cultivated Soils

Carbon to nitrogen ratios in different horizons of virgin and cultivated soils are shown in Table 18. These ratios have been calculated from the total organic carbon and total nitrogen data. Separate tabulations have been made for each zone.

TABLE 18.—AVERAGE CARBON TO NITROGEN RATIOS IN DIFFERENT HORIZONS OF VIRGIN AND CULTIVATED SOILS OF VARIOUS SOIL ZONES

Soil zone	Virgin or cultivated av. no. years cult.	Number of locations or samples	Surface horizon C/N	Subsurface horizon C/N	Virgin or cultivated av. no. years cult.	Number of locations or samples	Subsoil horizon C/N
Brown	0	13	12.1	10.7	0	4	11.6
Brown	17	13	11.3	10.0	13	4	10.2
Dark brown	0	20	12.3	10.9	0	3	10.4
Dark brown	22	20	11.6	10.4	16	3	10.4
Black	0	22	12.6	11.5	0	3	12.5
Black	26	22	12.3	11.1	29	3	11.1
Black-transition	0	7	11.8	10.9	0	6	10.5
Black-transition	24	7	11.1	10.3	21	6	9.6
Gray-transition	0	4	10.7	8.2	0	4	8.2
Gray-transition	12	4	10.5	8.2	12	4	8.2
Gray	0	15	17.2	12.1	0	8	11.3
Gray	14	15	15.9	12.1	14	8	10.6

In the brown, dark brown and black soils the average carbon to nitrogen ratio varied only from 10.0 to 12.6. In each of these soil zones the ratio was slightly lower for the subsurface soil (approximate depth 6 to 12 inches) than for the surface soil (approximate depth 0 to 6 inches), and the average ratio in each case was slightly lower in the cultivated soil than in the virgin soil. In the gray soils the average ratio was distinctly lower in the cultivated surface soil than in the virgin and the average ratio was much higher in the surface gray soils than in any other zone soils. The ratio was 15.9 for the cultivated surface soil and 17.2 for the virgin. The average ratio for the gray subsurface soils was 12.1, which is quite similar to that of the other soil zones.

DISCUSSION

All samples of soil were analysed for total organic carbon in order to determine their organic matter content. All samples were analysed for total nitrogen also, because this element is generally required in greater quantity than any other element obtained from the soil by non-legume crops, and nitrogen is frequently a limiting element in crop production. Nitrogen is held in the soil mainly in the form of organic matter, and there is a correlation between the quantities of nitrogen and organic carbon present, as shown in the tables.

The total losses of organic carbon and nitrogen increased with increase in original organic matter content, as might be expected under conditions favourable to decomposition provided by cultivation. Thus the black and black-transition soils have on the average lost most organic matter and nitrogen, whereas the brown and gray soils have lost the least.

The percentage losses, on the other hand, were much alike on the average from the surface 6 inches of brown, dark brown, and black soils, and amounted on the average to about 20% of the original content. The higher average loss of about 30% in the case of the gray soils may be due to the more active or less decomposed condition of the surface forest litter incorporated with the soil when it is first ploughed and cultivated. A more active condition is indicated by the higher carbon to nitrogen ratio of the organic matter present in the upper 6 inches of the gray soils. This ratio was 17.2 for the virgin and 15.9 for the cultivated, whereas the average ratios for the brown, dark brown, and black soils varied only from 10.0 to 12.6.

Both total losses of organic carbon and nitrogen, and percentage of original content losses from the 6- to 12-inch depth were small on the average as compared to the losses from the upper 6-inch depth. This was to be expected because of the relatively low original organic matter content of the 6- to 12-inch depth and because this subsurface layer is less exposed to the effects of cultivation.

Although the average losses of carbon and nitrogen from the upper 6 inches of brown, dark brown, and black soils were only about 20% of the original content (the corresponding losses from the gray soils were about 30%), the losses at different locations were quite variable. In some cases the losses were as great as approximately 50% of the organic carbon and 40% of the nitrogen, whereas in other cases there was no apparent loss.

Therefore in some cases the losses were more serious than the average losses might suggest. However, it must be admitted, as stated elsewhere, that in most cases it was not possible to prove the statistical significance of losses at individual locations.

Soil variability is an important factor in an investigation of this nature. In most cases it was not possible to prove the statistical significance of the losses at a given location, and it was necessary to take samples at a number of locations in order to obtain statistically significant average losses.

The average losses of nitrogen were not as great as those previously determined by Shutt at several locations in the Prairie Provinces (12), but the trends were similar.

Information regarding effects of different crop rotations on the nitrogen content of prairie province soils is being provided by studies in progress at the Division of Chemistry, Science Service, Department of Agriculture, Ottawa. Results obtained in these experiments have been summarized recently by Hopkins and Leahey (6).

Rotations which include legumes and grasses and the addition of farm manure evidently do reduce the losses of organic matter and nitrogen as compared to the losses under grain and fallow rotations. Sometimes gains of organic matter and nitrogen are produced by rotations of the former type. The grain and fallow rotations carried on for 25 to 30 years at Lethbridge, Lacombe and Indian Head, prior to the date of sampling the soil for the analyses shown in this report, all resulted in very large losses of organic carbon and nitrogen. On the other hand the equally old rotations at Lethbridge, Lacombe and Indian Head which included legumes, or legumes and grasses, and barnyard manure, resulted in but small losses of organic carbon and nitrogen at Lethbridge, small gains at Lacombe, and, at Indian Head, much smaller losses than those resulting from the grain and fallow rotation.

At Breton, where the rotation including clover had been carried on for only 8 years prior to the date of sampling (although the field had been under cultivation for 14 years), there was little difference between the composition of the soil under a rotation including clovers and under continuous wheat. The losses of organic carbon from the four cultivated plots analysed, including two which had received complete commercial fertilizer, were greater than the average loss from the gray soils, and the losses of nitrogen were about average. Apparently the period of different treatments was not long enough to produce any marked difference in organic carbon or nitrogen content.

Evidently the losses of organic matter and nitrogen are greatest after the land is first broken, and tend to decrease in later years. The average annual loss of organic carbon from the older cultivated fields (cultivated on the average for 28.5 years) was approximately half that of the newer cultivated fields (cultivated on the average for 9.2 years), and the average annual loss of nitrogen from the older cultivated fields was less than two-thirds that of the newer fields. Thus there is a tendency to reach an equilibrium point, even under a grain and fallow system, at which losses

caused by decomposition, crop absorption and other factors are balanced by gains in organic matter from plant growth, and gains in nitrogen due to non-symbiotic nitrogen fixing bacteria. However, it seems fairly certain that soil fertility would be seriously impaired at this point.

The percentage of organic carbon and nitrogen present at the point of equilibrium would vary no doubt with the different soil zones and with the types of soil within a given zone. In semi-arid western Kansas, Gainey, Sewell and Latshaw (5) found that an equilibrium point is reached at about 0.1 % nitrogen and they suggested that this is higher than the corresponding equilibrium point for soils of humid regions. However, many light textured semi-arid soils in the Prairie Provinces of Canada contain much less than 0.1% nitrogen. The equilibrium point for a heavy textured soil which had produced wheat continuously for over 90 years under humid climatic conditions at Rothamsted in England, was found to be approximately 0.1% (10).

It has been calculated that on the average one-third to one-half, approximately, of the nitrogen lost from the surface 6 inches of cultivated soil in the brown, dark brown, black and gray soil zones was absorbed by the crops grown on the soils. The large proportion of unaccounted for nitrogen may have been lost in various ways. It is quite likely that erosion by wind and water often plays a part in soil deterioration under cultivation even when their effects are not readily observable. Fields that were obviously eroded were not sampled in the course of this investigation.

It is commonly stated that the light coloured gray wooded soils become darker in colour and presumably richer in organic matter under cultivation. However, this darker colour is apparently due rather to the mixing of the surface organic matter with the light coloured leached layer below because decreases in percentage of organic matter and nitrogen greater on the average than those found in the parkland and prairie areas have taken place in these gray wooded soil areas, under the grain and fallow system. One would expect that under the fairly moist climatic conditions of the gray soil zone the nitrogen and organic matter content of soils as deficient in organic matter and nitrogen as these could be at least maintained and probably increased under cultivation, provided that a rotation were followed which included legumes and grasses and the use of barnyard manure, and commercial fertilizers as required.

In this investigation an attempt was made to sample cultivated and adjacent uncultivated soils that were uniform in texture and profile, and free from erosion or drifting, although admittedly it is probably impossible to avoid erosion entirely. Therefore this investigation has little or nothing to do with obvious erosion by wind and water which in some local instances has completely ruined the soil for arable purposes. However, the deterioration measured is probably fairly representative of that of the great majority of prairie province soils which have been farmed by the commonly practised grain and fallow system.

Prior to the initiation of this investigation comparatively few actual determinations of the extent of the losses of nitrogen and organic matter, in relation to general fertility, from prairie province soils, had been made. Reports of losses were commonly based upon observation rather than actual

determinations, and some of these reports have tended to exaggerate and some to minimize the extent of such losses. The losses have been large under the grain and fallow system of farming, amounting on the average, in a period of about 22 years, to approximately one-fifth of the original nitrogen and organic matter content, in the cases of the brown, dark brown, and black soils, and a larger proportionate loss in the case of the gray soils, but not as large as sometimes suggested, and the land in most cases is far from utterly ruined. However, the importance of adopting measures such as the introduction of grasses and legumes into the rotation with grain crops to maintain the fibre and fertility of the soils, where such action has not already been taken, can hardly be over-emphasized, and for this reason there may be some excuse for exaggerating the extent of the losses which have already taken place.

While the grain and fallow system of farming had undoubtedly been responsible for the loss of large quantities of organic matter and fibre from the soils, and while the importance of growing grasses and legumes in rotation with grain crops should be emphasized, it must be admitted that it is very unlikely that the organic matter content of soil consisting originally of prairie grassland could be maintained at its original level under any practical system of cultivation without irrigation. It is generally recognized that the organic matter content of soil under grass tends to be increased, or maintained at a relatively high level, if not overgrazed, as compared to land under cultivation. Some losses of organic matter, fibre, and nitrogen must therefore be expected, but these should not be such as to seriously impair the productivity of the soil.

In any discussion of soil fertility and productivity the importance of weed control should be emphasized. Many serious weeds can be kept under control most economically by seeding the land down to sod forming crops periodically. Such crops help to control various insect pests and plant diseases also.

Serious losses of organic matter and fibre and impairment of physical condition, in the drier regions, and consequent soil deterioration through erosion, may be guarded against by growing grasses in rotation with grain crops (in addition to maintaining a trash cover of stubble and straw on summerfallowed land). In the moister regions both grasses and legumes may be grown in the rotations in order to guard against serious impairment of the soil's physical condition, organic matter content, and fertility. These should be supplemented by the use of barnyard manure where available, and by the use of commercial fertilizers where profitable. It is often impractical to grow a legume in rotation with grain crops in the drier regions of the prairie provinces, but it is commonly practical in such regions to seed the land down to a drought resistant grass for a few years, periodically, and thus restore fibre and organic matter to the soil.

SUMMARY

An extensive investigation has been made of the effects of cultivation and cropping systems (mainly the commonly practised grain and fallow system) on the chemical composition of prairie province soils, by comparing the composition of virgin and adjacent cultivated soils.

The samples of cultivated soil were obtained from recently broken fields as well as older cultivated fields, the average period of cultivation being just over 22 years.

More than 1000 composite or individual samples of soils from 85 locations in Alberta, Saskatchewan and Manitoba (representing 85 comparisons of virgin and cultivated soil) have been analysed for total organic carbon and nitrogen.

The losses in percentage of original organic carbon content from the surface 6 inches of brown, dark brown, and black soils were much alike on the average, and amounted to about 20% of the original content.

The losses in percentage of original nitrogen content from the surface 6 inches of brown, dark brown, and black soils were also much alike on the average, and amounted to about 18% of the original content.

The losses in percentage of original organic carbon and nitrogen content from the surface 6 inches were greatest in the case of the gray soils, amounting on the average to about 30% of the original content.

Both total losses and percentage of original organic carbon and nitrogen content losses from the subsurface or 6- to 12-inch depth were small on the average as compared to the losses from the upper 6-inch depth.

The average losses of organic matter, in pounds to the depth of 12 inches, from the different soil zones were as follows: brown, 25,566; dark brown, 32,289; black, 62,935; black-transition, 92,115; gray-transition, 39,632; gray, 28,253.

The average losses of nitrogen, in pounds, to the depth of 12 inches, from the different soil zones were as follows: brown, 889; dark brown, 1208; black, 2658; black-transition, 3662; gray-transition, 2455; gray, 1308.

The black and black-transition soils, originally high in organic matter, have lost most organic carbon and nitrogen, whereas the brown and gray soils, originally relatively low in organic matter, have lost the least.

The losses were quite variable. At some locations the losses were as great as approximately 50% of the original organic carbon and 40% of the nitrogen, whereas in other cases there was no apparent loss.

It was calculated that on the average one-third to one-half, approximately, of the nitrogen lost from the surface 6 inches of cultivated soil in the brown, dark brown, black and gray soil zones, was absorbed by the crops grown on the soils.

The average losses of organic carbon and total nitrogen from the surface 6 inches of the brown, dark brown, black (including black-transition), gray (including gray-transition) and gray soils, were significant in all cases. The losses of organic carbon from the subsurface, or 6- to 12-inch depth, were significant in all cases also, and the losses of total nitrogen were significant in the cases of the black (including black-transition) and gray soils.

Rotations which included legumes and grasses, and the addition of barnyard manure, as carried on for 25 to 30 years at the Lethbridge, Lacombe and Indian Head Dominion Experimental Stations, reduced or

prevented losses of organic matter and nitrogen, as compared to the large losses which resulted from the equally old grain and fallow rotations at the same stations.

The average annual loss of organic carbon from the older cultivated fields (cultivated on the average for 28.5 years) was approximately half that of the newer cultivated fields (cultivated on the average for 9.2 years), and the average annual loss of nitrogen from the older cultivated fields was less than two-thirds that of the newer fields.

The average carbon to nitrogen ratio of the surface 6 inches of brown, dark brown, and black soils varied only from 11.3 to 12.6, whereas the corresponding ratio of the gray soils was 17.2 for the virgin and 15.9 for the cultivated.

Cultivation has tended to produce a narrower carbon to nitrogen ratio in the surface soil.

The carbon to nitrogen ratio of the 6- to 12-inch depth is narrower on the average than that of the surface 6 inches.

ACKNOWLEDGMENT

This investigation was made possible by a grant from the Dominion Department of Agriculture, Experimental Farms Service P.F.R.A.

A. C. Caldwell, now Assistant Professor of Soils, University of Minnesota, did the earlier analytical work on this project, and A. M. Dean has been working on special phases of the project recently.

REFERENCES

1. ALLISON, L. E. Organic soil carbon by reduction of chromic acid. *Soil Sc.* 40 : 311-320. 1935.
2. BROWN, A. L., F. A. WYATT and J. D. NEWTON. Effects of cultivation and cropping on the chemical composition of some Western Canada prairie soils, Part II. *Sci. Agr.* 23 : 229-232. 1942.
3. CALDWELL, A. C., F. A. WYATT and J. D. NEWTON. Effects of cultivation and cropping on the chemical composition of some Western Canada prairie soils. *Sci. Agr.* 19 : 258-270. 1939.
4. DETURK, E. E. Changes in the soils of the Morrow plots which have accompanied long-term cropping. *Pro. Soil Sci. Soc. Am.* 3 : 83-84. 1938.
5. GAINES, P. L., M. C. SEWELL and W. L. LATSHAW. The nitrogen balance in cultivated semi-arid western Kansas soils. *J. Am. Soc. Agron.* 21 : 1150-1153. 1929.
6. HOPKINS, E. S. and A. LEAHEY. Crop rotations in the prairie provinces. Dominion of Canada—Department of Agriculture Publication 761. *Farmers Bulletin* 124. 1944.
7. METZER, W. H. Nitrogen and organic carbon of soils as affected by crops and cropping systems. *J. Am. Soc. Agron.* 28 : 228-233. 1936.
8. METZER, W. H. Nitrogen and organic carbon of soils as influenced by cropping systems and soil treatments. *Kansas Agr. Exp. Sta. Tech. Bull.* 45. 1939.
9. OFFICIAL AND TENTATIVE METHODS OF ANALYSIS OF THE ASSOCIATION OF OFFICIAL AGRICULTURE CHEMISTS. 4th ed. 1935.
10. RUSSELL, E. J. and J. D. WATSON. The Rothamsted field experiments on the growth of wheat. *Imperial Bureau of Soil Science Technical Communication.* No. 40. 1940.
11. SALISBURY, A. F. and W. A. DELONG. A comparison of the organic matter of uncultivated and cultivated Appalachian upland podsol soils. *Sci. Agr.* 21 : 121-132. 1940.
12. SHUTT, F. T. Influence of grain growing on the nitrogen and organic matter content of the western soils of Canada. *Dom. of Can. Dept. of Agr. Bull.* 44 N.S. 1925

ERRATUM

In the article entitled, "Pink rot disease of potatoes in¹ British Columbia", by Walter Jones, June 1945 issue of *Scientific Agriculture* (Vol. 25, No. 10, p. 597), the legends under Plates I and II should be interchanged.

NOTICE

In order that the Volume year of *Scientific Agriculture* may coincide with the calendar year, publication will be suspended during the months of September, October, November, and December of 1945. Volume 26 of *Scientific Agriculture* will appear on January 1, 1946.

All subscribers have been duly notified and the necessary arrangements have been made in connection with the payment of subscription dues.

SOME FACTORS AFFECTING APPLE YIELDS IN THE OKANAGAN VALLEY

II. SOIL DEPTH, MOISTURE HOLDING CAPACITY, AND pH¹

J. C. WILCOX²

Dominion Experimental Station, Summerland, B.C.

[Received for publication January 25, 1945]

This paper is the second in a series reporting the findings of an investigation started in 1937 into the effects of certain factors on apple tree performance in the Okanagan Valley in British Columbia. The first paper (25) dealt with tree size, tree vigour, biennial bearing, and distance apart of planting. This present paper deals with soil depth, moisture holding capacity, pH, and lime content.

REVIEW OF LITERATURE

A great deal of investigational work has been reported on the effects of the physical and chemical nature of the soil on fruit tree performance. It will be considered sufficient here to review briefly some of the more important findings dealing with the effects of the physical nature and pH of the soil on apple tree growth and yield.

Physical Nature of Soil

Among the most important factors associated with the physical nature of the soil are texture, depth, moisture holding capacity, hard-pan, and natural drainage. Texture and depth are very closely related to the moisture holding capacity, as reported previously by the author (26). In 1915, Wilder (28) recommended for the Baldwin variety a medium to semi-light soil, and for the McIntosh a soil somewhat heavier³ than this. In 1930, Heinicke and Batjer (7) in New York found a clay subsoil to be deleterious to the growth of apple trees. In 1932, Collison, Collison and Harlan (4) reported that the sand content of a New York soil was positively correlated with the yield of Baldwin, but not with the yield of Greening. The same year, Veatch and Partridge (23) and Partridge and Veatch (19) in Michigan found too light or shallow a soil to be undesirable, as also was an acid hardpan or clayey subsoil; and Oskamp and Batjer (17) in New York reported that a deep loam soil was best suited to the growth of Baldwin trees. A clay subsoil or hardpan and a high water table were not conducive to good tree performance. At various times since then, Oskamp

¹ Contribution No. 652 from the Division of Horticulture, Experimental Farms Service, Dominion Department of Agriculture, Ottawa, Canada.

² Assistant Superintendent at the Dominion Experimental Station, Summerland, B.C., in charge of nutritional investigations with tree fruits.

³ In this paper, a "light" soil is used to mean a sandy soil, and a "heavy" soil is used to mean a fine silt or clay soil.

and his co-workers (1, 14, 15, 16) have reported similar findings with New York soils. In 1933, Oskamp (14) obtained a positive correlation between depth to the ground water table and the yield of Baldwin trees. In 1934, Veatch and Partridge (24) in Michigan recommended light to heavy loams, underlaid at 10 to 15 inches depth by a heavy loam, penetrable for tree roots to 10 feet or more. In 1935, Sweet (22) recommended a deep soil: one that is not too light, with too low a moisture holding capacity; and not too heavy, with too little permeability to water and air. Good soil structure and drainage were stressed. Similar recommendations have been made since by Magness, Degman and Furr (10), Partridge and Veatch (20), Morgan, Gourley and Albeiter (13), Browning and Sudds (2) and Magness (9). It appears to have been generally agreed (14, 16, 20) that for best results a depth of at least 5 feet of soil free from hardpan or excess water is required. Oskamp (14) found a good positive correlation between yield and the depth of the water table. Magness (9) stressed the importance of the moisture holding capacity of orchard soils. Gardner, Bradford and Hooker (6) felt that the varietal preferences reported by Wilder and others are open to question. It should be noted that all of these references dealt primarily with non-irrigated areas.

Soil pH

Little appears to have been reported on the effects of soil pH on apple tree performance. In 1932, Oskamp and Batjer (18) in New York reported that within a pH range of 5.4 to 7.8 there was a good negative correlation between pH and yield with Baldwin; but that the correlation was not significant with Greening. In 1934, Veatch and Partridge (24) in Michigan were unable to specify any definite optimum within a pH range of 4.5 to 7.5. In 1937, Morgan (12) in Connecticut suggested a pH range of 5.4 to 6.8 as being desirable for apples. In 1941, Spurway (21) in Michigan specified a pH range of 5.0 to 6.5 as being the optimum for apples. Morgan, Gourley and Albeiter (13) considered the apple to be adapted to a wide pH range, but cautioned against the use of soils sufficiently alkaline to cause chlorosis. Loughridge (8) listed the apple as being highly susceptible to injury from sodium carbonate, which produces black alkali in the soil.

The relation between the lime content and the pH of the soil has received considerable attention. Buehrer and Williams (3) found that when no black alkali was present, soil with 20% lime had a pH of around 7.5; with 70% lime, a pH of around 8.0. McGeorge (11) found calcareous soils containing no alkali to range around pH 8.0.

Tree Records

PROCEDURE

In the first paper of this series (25), the general experimental set-up and the procedures used in obtaining the tree records were described. Groups of 5 mature or nearly-mature McIntosh trees were selected in grower-owned orchards from Penticton to Oyama. Annual records were taken for 6 years (1937 to 1942) on trunk circumference, terminal length, total yield, and "profitable" yield. This last consisted of fruits falling within the diameter range of $2\frac{1}{4}$ to $3\frac{1}{8}$ inches, and showing 20% or more of solid red colour. From the trunk circumference was calculated the "trunk-ground ratio," a measure of tree size per unit area of ground occupied; and

from the yields was calculated the "biennial bearing index," a measure of the degree of biennial bearing. These data were all averaged for 4-year or 5-year periods, depending on their biennial bearing status.

For the purpose of comparison with the soils data, the tree data have all been averaged for each plot. The results are presented in Table 3 in the Appendix.

Soil Sampling

Soil samples were obtained from all plots during the months of April and May, 1940. In each plot, composite samples were taken around one tree only. The procedure used was as follows:

- (1) Make borings with a 1½-inch auger at each tree, and from the data thus obtained select the tree around which the soil appears best to represent the plot.
- (2) At distances of 4, 7 and 10 feet from the trunk, lay out a pattern of ten locations around this tree.
- (3) At each location, take a sample with the auger at a depth of 0 to 8 inches, and composite these samples. Mix thoroughly, pass through a 3-mm. screen, allow both soil and screenings to air dry, and weigh them to obtain the percentage of gravel larger than 3 mm. Discard the gravel.
- (4) In similar manner, make a composite from ten samples at the 8- to 24-inch level, and from five samples at the 24- to 60-inch level. If a mixture of clear sand and gravel is encountered above 60 inches, sample the top of this mixture only.

The three depths of sampling were selected after considerable study of root growth. The 0- to 8-inch depth was found to represent (usually) the area of greatest concentration of cover crop roots, combined with a low concentration of apple roots; the 8- to 24-inch depth represented the greatest concentration of apple roots; and the 24- to 60-inch depth represented a lesser concentration again of apple roots. In some soils, the roots descended much deeper than this, but they were usually sparsely scattered at the lower depths. The data on root growth will be reported in a subsequent paper.

Moisture Holding Capacity

The moisture holding capacity, expressed in inches of water per foot of soil (M.C.F.), was determined by the settling volume procedure outlined in a previous paper by Wilcox and Spilsbury (26). The following equation was used to transfer settling volume to moisture holding capacity:

Moisture holding capacity (M.C.F.) = $0.0760 \times \text{settling volume} - 0.321$.

Each figure thus obtained was multiplied by the depth in feet, to obtain the amount of water held at each of the three depths. These were then added together, to obtain the amount held in the whole profile to the depth sampled. The purpose of this procedure has been discussed in a previous paper by Wilcox and Spilsbury (27). In making the calculations, corrections were made for the percentage of gravel over 3 mm., on the assumption that its moisture holding capacity was zero. Thus if the screened soil had a moisture holding capacity of 4.0 inches, but the gravel content of the unscreened soil was 25%, then the correct (adjusted) moisture holding capacity was assumed to be 75% of 4.0, or 3.0 inches. It was also assumed that the underlying mixture of coarse sand and gravel, found in many plots, had a moisture holding capacity of zero.

Lime Content of Soil

The approximate amount of carbonates present in the soil was determined by a quick test developed by the author. To establish a standard for this test, increasing amounts of C.P. calcium carbonate were mixed thoroughly in samples of a number of soils that originally showed no effervescence with hydrochloric acid. These mixtures (0 to 7% calcium carbonate) were treated by the same procedure as the unknowns, and from the data obtained a curve was established relating the lime content to the froth readings. The readings obtained from the unknowns were then transferred into carbonate readings, expressed in terms of lime content. The procedure used in obtaining the readings was as follows:

Pour about 5 ml. of water into a tall 100 ml. graduated cylinder. Add 10.0 gm. of air-dried soil. Insert a long, strong stirring rod. Make up to 20.0 ml. with water, washing down the soil adhering to the side of the cylinder with it. Add in one motion 10.0 ml. of 1 normal hydrochloric acid, stir vigorously, and note the maximum height to which the froth rises. Determine carbonate content from chart.

Readings were made in duplicate, or in triplicate if the first two were not close enough together. The results shown in Column 7 of Table 4 are the averages, adjusted for gravel content.

Soil pH

The pH was determined with a glass electrode. Boiled distilled water was added to the soil until a "pasty" condition was obtained, as suggested by Doughty (5). The difference between the pH at this moisture content and that at the moisture holding capacity was found to be scarcely measurable in most cases. Readings were made in duplicate, or in triplicate if the first two were more than 0.1 pH apart. The results shown in Column 6 of Table 4 are the averages. The pH values of the different soil levels were averaged to obtain the "average" pH for each profile.

Statistical Procedures

The data obtained were examined statistically by means of correlations, regression lines, and scatter diagrams, as outlined in the first paper (25) of this series. The soils data were obtained from 74 plots, but the tree data were considered reliable from only 66 of these plots. These figures are mentioned in order to assist in interpreting the significance of the correlations reported below.

RESULTS

The more pertinent of the data on which this report is based are tabulated in the Appendix. In Table 3 are shown the number of trees per plot, the trunk-ground ratio (a measure of tree size per unit area of ground), and the plot averages of terminal length, biennial bearing index, total yield per acre, and profitable yield per acre. These were all calculated from the "Summary" data described and presented in Paper I (25) of this series. In Table 4 are shown the soil depth, gravel content, moisture holding capacity per soil layer and per profile, moisture holding capacity per foot of soil, pH, and lime content.

Soil Depth

Only 22 plots out of 75 had five feet or more of soil that could be classed as suitable for normal root growth. As will be seen from Column 2 of Table 4, a high percentage of the plots had only about two feet of soil. Where the soil was less than 60 inches in depth, it was in all cases underlaid by a mixture of clear gravel and coarse sand, in various proportions. Where the soil was deeper than 60 inches, no attempt was made to determine its actual depth. There was no evidence of poor drainage in any of the plots. Such cases do occur in the Okanagan Valley, but care was taken to avoid them in the original selection of plots.

An examination of the data revealed that neither soil depth nor soil texture by itself was as important in influencing tree performance as were the two of them taken together. A convenient method of combining them was found to be in the form of the moisture holding capacity, expressed in inches of water (26); and this has therefore been the method used as a basis for making correlations.

Moisture Holding Capacity

The moisture holding capacity was expressed first as inches of water per foot of soil; and these figures were then adjusted for the gravel content, on the assumption that particles over 3 mm. in size had a moisture holding capacity of zero. The moisture holding capacity was reported previously (26) to show a high positive correlation with the colloid content, and a high negative correlation with the sand content. It was used in this investigation, therefore, as a convenient index of average soil texture.

TABLE 1.—RANGE OF EACH SOIL MEASUREMENT

Soil measurement	Soil depth	Minimum	Maximum	Mean
	inches			
Depth, in inches		17	60*	38.3
Gravel content (over 3 mm.) in per cent	0- 8	0	62.5	7.1
	8-24	0	64.0	20.8
	24-60	0	43.0	4.0
Moisture holding capacity, in inches of water per foot of soil†	0- 8	1.23	4.32	3.20
	8-24	0.94	4.62	2.84
	24-60	1.34	4.67	3.39
Moisture holding capacity, in inches of water per profile‡	0-60	2.86	23.05	9.19
Lime content, in per cent‡	0- 8	0	1.4	0.03
	8-24	0	3.6	0.39
	24-60	0	6.2	2.31
pH	0- 8	5.67	7.64	6.54§
	8-24	5.98	8.19	6.97§
	24-60	6.65	8.34	7.52§
	0-60	5.91§	8.03§	6.91§

* The soil was not sampled below a depth of 60 inches.

† The moisture holding capacity has been adjusted for gravel content, on the assumption that particles over 3 mm. in diameter have a moisture holding capacity of zero. The mixture of coarse sand and gravel underlying the soil at varying depths was ignored. The lime content has also been adjusted for per cent gravel.

‡ Measured to the actual soil depth, the maximum of which was 60 inches.

§ Unweighted averages.

As will be seen from Table 1, there were wide variations both in the gravel content and in the moisture holding capacity. For the most part, the shallow soils had high gravel contents. Most of them also had low moisture holding capacities, even without adjusting for the gravel. On the other hand, the deeper soils contained very little if any gravel and had high moisture holding capacities. About one-half of the plot soils could be classed as shallow and sandy, about one-quarter as deep and heavy, and about one-quarter as intermediate in depth and texture.

Some correlations of the moisture holding capacity with the pH and with the tree data are presented in Table 2. The pH correlations are discussed below under "pH." The profile total of the moisture holding capacity (representing a combination of soil depth and texture) showed significant (odds 19 : 1 or better) or highly significant (odds 99 : 1 or better) positive correlations with terminal length, total yield, and profitable yield, and a significant negative correlation with biennial bearing index. In other words, the trees on the heavier and deeper soils tended to be more vigorous, to bear more regularly, and to have higher yields of both total and profitable fruit. Adjusting the total yield for differences in terminal length and biennial bearing index lowered the correlation somewhat. It appears that the higher yields found in the better soils could be attributed in part to better vigour and more regular bearing, and in part to other factors. Some of these other factors will be discussed in subsequent papers in this series.

TABLE 2.—SOME CORRELATIONS BETWEEN SOIL PROPERTIES AND TREE PERFORMANCE

Two sets of data correlated		Coefficient of correlation
M.C.F., *0- 8 inches	pH, 0- 8 inches	+ .084 (NS)§
M.C.F., 8-24 inches	pH, 8-24 inches	+ .554 (HS)
M.C.F., 24-60 inches	pH, 24-60 inches	+ .672 (HS)
Moisture capacity, profile total	pH, profile average	+ .586 (HS)
Moisture capacity, profile total	Trunk-ground ratio	+ .013 (NS)
Moisture capacity, profile total	Terminal length	+ .262 (S)
Moisture capacity, profile total	Biennial bearing index	- .267 (S)
Moisture capacity, profile total	Total yield	+ .410 (HS)
Moisture capacity, profile total	Total yield, 3 adjustments†	+ .272 (S)
Moisture capacity, profile total	Profitable yield	+ .393 (HS)
pH, profile average	Trunk-ground ratio	+ .020 (NS)
pH, profile average	Terminal length	+ .060 (NS)
pH, profile average	Biennial bearing index	- .038 (NS)
pH, profile average	Total yield	+ .267 (S)
pH, profile average	Profitable yield	+ .259 (S)
pH, 0-8 inches	Total yield	+ .151 (NS)
pH, profile average	Total yield, with M.C.F. effects eliminated‡	+ .036 (NS)
pH, profile average	Profitable yield, with M.C.F. effects eliminated‡	+ .039 (NS)

* M.C.F. Moisture holding capacity per foot of soil. It has been adjusted for the per cent gravel.

† Yields adjusted for all three of trunk-ground ratio, terminal length and biennial bearing index. All other yields noted in this table have been adjusted for trunk-ground ratio only.

‡ Partial correlations, with the M.C.F. held constant.

§ NS—Non-significant, with odds lower than 19 : 1.

S—Significant, with odds between 19 : 1 and 99 : 1.

HS—Highly significant, with odds higher than 99 : 1.

The scatter diagram of total yield plotted against total moisture holding capacity per profile is shown in Figure 1. It will be seen that although the general trend was a positive one, there were some fairly low yields on heavy, deep soils (i.e. those with high moisture holding capacities), and some fairly high yields on light, shallow soils. If the two plots with exceptionally high yields are ignored, there appears to have been a fairly steady increase in the maximum yield attained at each moisture holding capacity as this factor has increased. The differences in maximum (or "possible") yield that could be attributed to soil depth and texture alone, however, were not more than about 200 loose boxes per acre. The scatter diagram of profitable yield plotted against moisture holding capacity is very similar to that in Figure 1.

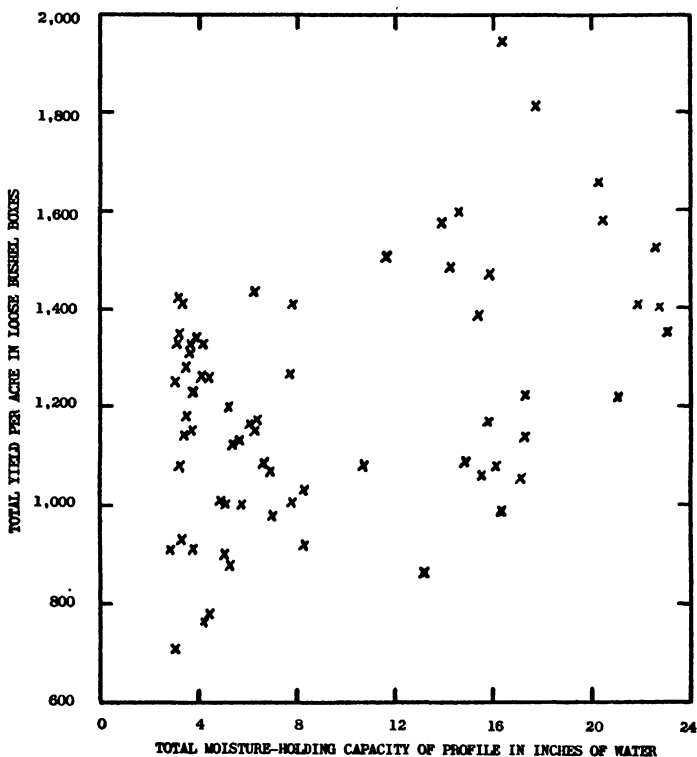


FIGURE 1. Scatter diagram of total moisture holding capacity of soil to 60 inches plotted against total tree yield. ($r = +.410$.)

Lime Content of Soil

Lime was present in the surface 8 inches of soil in only a very small percentage of the plots. It was suspected that wherever the lime appeared at or close to the surface, the original surface soil had been lost by erosion, or had been removed in levelling the soil prior to planting.

The presence of lime in the soil below a depth of 8 inches depended primarily on the texture of the soil. In sandy soil, no lime at all was recorded in the 8- to 24-inch layer, and almost none in the 24- to 60-inch layer. In the heavier soils, however, lime was usually present in moderate

amount in the 8- to 24-inch layer and in still higher amount in the 24- to 60-inch layer. Thus the heavier and deeper the soil and the higher the total moisture holding capacity, the higher also was the average lime content of the profile. Owing to the fact that so many of the profiles showed no free lime, no attempt was made to calculate any coefficients of correlation involving lime content.

Soil pH

The pH was affected by soil depth, soil texture, lime content, and fertilizers applied. The effects of the fertilizers will be reported in a subsequent paper.

Since the lime content of the soil was so closely related to soil depth and soil texture (as just noted), it was found difficult to separate entirely the effects of these three factors from one another. The presence of lime raised the pH to above 7.3 in every case, and usually to around 8.0. The pH tended to increase both with an increase in the lime content and with an increase in depth. The highest pH recorded was 8.34 (see Table 1), and the lowest with lime present was 7.35. With no measurable lime present, the pH was usually below 7.0, though occasionally it was above this figure. In one case (Plot W10, 24 to 60 inches), the pH was 8.24 with no evidence of any free lime, indicating the possibility of the presence of a small amount of black alkali.

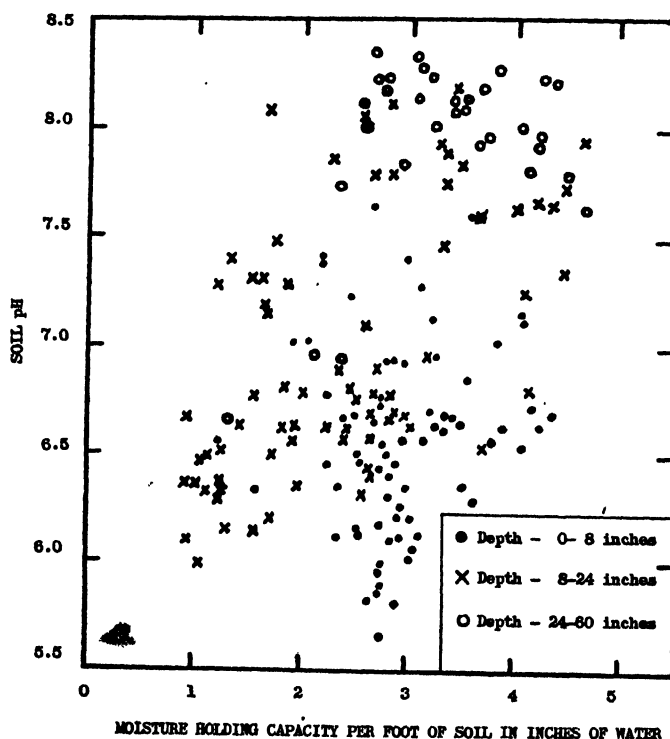


FIGURE 2. Scatter diagram of moisture holding capacity per foot of soil plotted against soil pH. Different marks are used for the three different soil depths. (At 0-8 inches $r = +.084$, at 8-24 inches $r = +.551$, and at 24-60 inches $r = +.672$.)

The pH varied with changes in the moisture holding capacity, and hence with changes in soil texture. Highly significant positive correlations were obtained between pH and moisture holding capacity per foot of soil in the 8- to 24-inch layer and in the 24- to 60-inch layer, but not in the 0- to 8-inch layer (Table 2). These relationships are illustrated in Figure 2. To some extent, the effect of soil texture is due to the presence of higher percentages of lime in the heavier soils. In the surface soils, however, the factor that has affected the pH the most appears to have been the cultural practices, more especially fertilizing and cover cropping.

The pH also varied with soil depth. In the heavy, deep soils there was almost invariably an increase in pH with increase in depth; but in a few of the light, shallow soils the pH was slightly lower in the 8- to 24-inch layer than in the 0- to 8-inch layer. The differences between the three layers studied are illustrated in Figure 2. When soil texture and depth were combined in the form of total moisture holding capacity per profile, this showed a highly significant positive correlation with the average pH of the profile (Table 2 and Figure 3). In other words, the heavier, deeper soils tended to have higher pH values than did the lighter, shallower soils.

The correlations between the average pH of the profile and tree performance are shown in Table 2. There was no evidence of any relationship between pH on the one hand and trunk-ground ratio, terminal length, or biennial bearing index on the other hand. There were significant positive correlations, however, between pH and yield (both total and profitable).

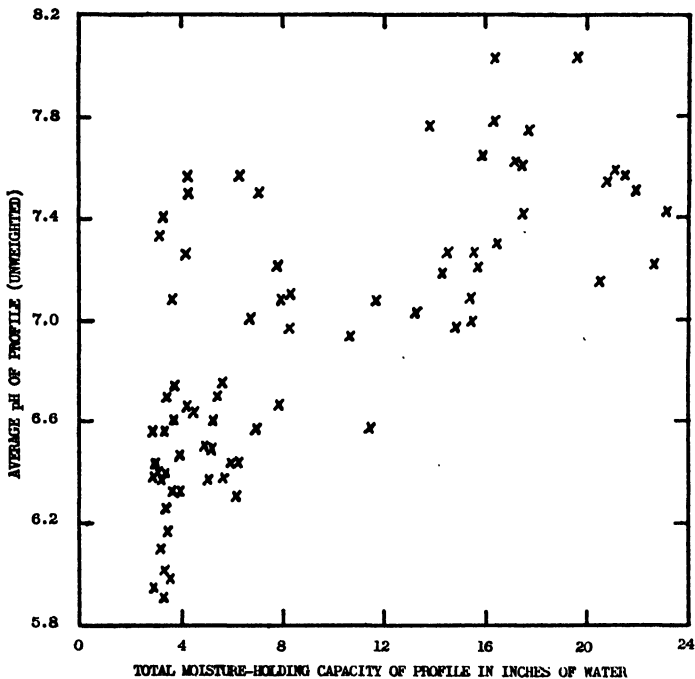


FIGURE 3. Scatter diagram of total moisture holding capacity of soil to 60 inches plotted against average pH of profile. ($r = +.586$.)

In other words, there was a distinct tendency for the higher yields to occur along with the higher average pH values. This is illustrated in Figure 4, showing total yield per acre plotted against average pH of profile. When

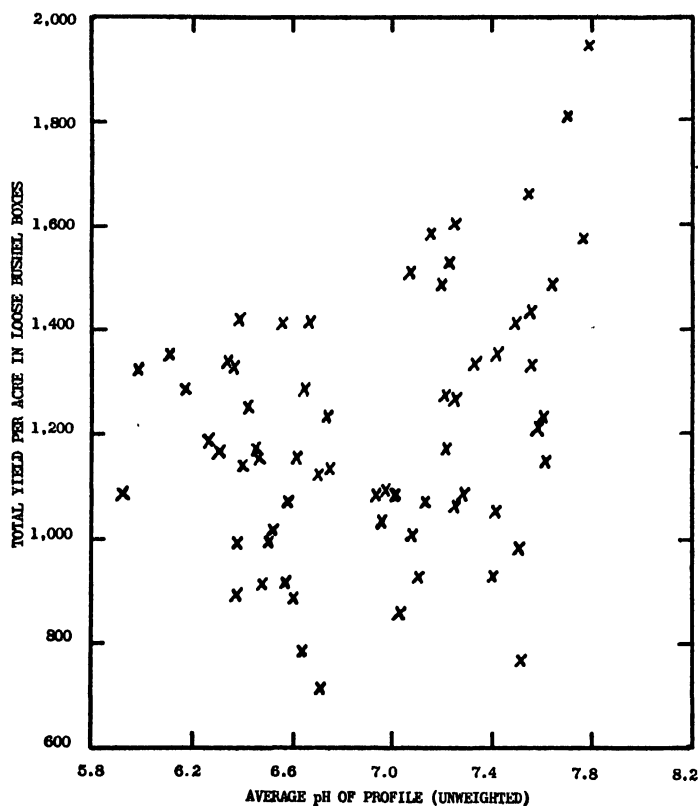


FIGURE 4. Scatter diagram of average pH of profile plotted against total tree yield. ($r = +.267$.)

the yield was correlated with the pH of the surface 8 inches only, the coefficient was positive and much lower in value. However, when the effects of moisture holding capacity were eliminated from the correlations between average pH and yield, the coefficients were reduced almost to zero, both with total yield and profitable yield. There is thus no proof that the pH of itself had any effect one way or the other on tree yield; in other words, the trees seem to have performed equally well at all points within the pH range of 6.0 to 8.0.

It should be noted that in the original selection of plots an attempt was made to avoid all areas showing black alkali; and as far as known, sufficient alkali was not encountered in any plot to cause injury to the plants. The positive correlation found between pH and yield appears to be due to some one or more factors (other than pH) that were closely associated with soil texture and depth.

DISCUSSION

It is of interest to compare the results obtained in this investigation with those reported by other workers. In New York (1, 4, 7, 17, 22), Michigan (20, 23), Virginia (2) and various other areas, heavy or slatey subsoils have been found to be deleterious to tree growth and production. The main reason for this has been the presence of poor drainage and a high water table, a combination frequently reported in the Eastern States and in Eastern Canada. Another reason has been the occasional presence of a true hardpan, which has been impervious not only to water but to tree roots as well. In the investigation reported herein, the deeper and heavier the subsoil (to a depth of 60 inches), the better on the average was the performance of the trees. However, there was in this case no high water table and no definite hardpan. There was no evidence of insufficient drainage in the plots studied. In some low-lying parts of the Okanagan Valley, seepage water is in evidence; but these areas were not encountered in this investigation. In only one case was there any evidence of root growth having been inhibited by a tight soil. As will be noted in a subsequent paper, the roots of apple trees were found to grow downward freely to a depth of at least 8 feet. One reason for this was that in the deeper soils the heaviest horizons (of laminated clay) were comparatively thin, and alternated with lighter layers rich in lime in a comparatively loose form. It is apparent from these findings that the presence of clay in the subsoil does not necessarily induce conditions unfavourable for normal tree growth.

Another relationship that does not conform to the findings of some other investigators is that found between soil pH and tree performance. In New York (18), a pH range of 5.4 to 7.8 was found to correlate negatively with yield of Baldwins. The optimum pH range specified for apples is 5.0 to 6.5 in Michigan (21) and 5.4 to 6.8 in Connecticut (12). In this present investigation, a pH range (profile average) of 5.91 to 8.03 was found to correlate *positively* with tree vigour and tree yield. By partial correlations, it was found that this correlation was caused not by any direct effect of soil pH on tree performance, but rather by a close relationship between soil pH on the one hand and soil depth and texture on the other hand. In other words, there was no evidence of either a beneficial effect or a deleterious effect of increasing pH within the range studied. This conforms to the findings of Veatch and Partridge (24) in Michigan.

It appears from this investigation that within a pH range of 6.0 to 8.0, any apparent effects of pH on tree performance cannot safely be attributed to pH alone; they are more likely to be due to other factors, with which the pH happens to be associated. In this case, the lowest pH values were found in the poorest soils, those that have been subject to the greatest leaching; and the highest pH values were found in the heaviest and deepest soils, which contain the greatest reserves of soil moisture and plant nutrients. In some other parts of the world, a high pH has no doubt been associated with certain undesirable conditions. In New York (18), for example, it appears in some case to have been associated with an impermeable subsoil.

SUMMARY

Growth and yield records were obtained from 74 plots (5 trees per plot) of McIntosh trees scattered through the Okanagan Valley from Penticton to Oyama. Soil samples were obtained in each plot at depths of 0-8 inches, 8-24 inches and 24-60 inches. Sampling was discontinued at the gravel if it was encountered at a lesser depth than 60 inches. Gravel content, moisture holding capacity (expressed both in per cent and in inches of water), lime content and pH were determined on each soil sample. The total moisture holding capacity per profile was used as a combination measurement of soil texture \times depth.

The depth of soil ranged from 17 inches to at least 60 inches, the gravel content from 0 to 43%, the moisture holding capacity from 1.34 to 4.67 inches per foot of soil and from 2.86 to 23.05 inches to a depth of 60 inches of soil, the lime content from 0 to 6.2%, the pH from 5.67 to 8.34, and the average pH per profile from 5.91 to 8.03.

In about one-quarter of the plots, the soil was comparatively heavy and at least 60 inches deep; in about one-half it was light and only 24 inches or less in depth; and in the remainder it ranged between these two groups in texture and depth. The deeper, heavier soils had, on the average, higher moisture holding capacities, more lime, and higher pH values than the lighter, shallower soils. In the deeper soils, both the lime content and the pH increased with depth. There was no evidence of true hardpan or of excess moisture in the soil in any of the plots selected for this study.

The more pertinent of the coefficients of correlation revealed the following trends: (1) The heavier and deeper the soil (as measured by the total moisture holding capacity to a depth of 60 inches), the higher was the average pH, the more vigorous were the trees, the less was the degree of biennial bearing, the higher was the total yield, and the higher was the yield of high quality fruit. (2) The higher the pH, the higher was the total yield. However, when the effects of moisture holding capacity were eliminated by partial correlations, there was found to be no direct relationship between pH and yield. There was no relationship found between pH on the one hand and tree vigour and biennial bearing on the other hand.

It is concluded that the deeper, heavier soils in the plots chosen showed better promise for good tree performance than did the lighter, shallower soils. Just what factors entered into this effect were not determined.

ACKNOWLEDGMENTS

The writer wishes especially to acknowledge his indebtedness to Dr. A. T. Knight (Graduate Assistant at the Dominion Experimental Station at Summerland in 1939 and 1940), who obtained the soil samples on which these studies were based. He also wishes to express his appreciation for editorial comment made by Mr. R. C. Palmer and Mr. W. M. Fleming of the Dominion Experimental Station at Summerland, British Columbia.

REFERENCES

1. BATJER, L. P. and J. OSKAMP. Soils in relation to fruit growing in New York. VII. Tree behavior on important soil profiles in the Kinderhook, Germantown, and Red Hook areas in Columbia and Dutchess Counties. New York (Cornell) Agr. Exp. Sta. Bull. 627. 1935.

2. BROWNING, G. M. and R. H. SUDDS. Some physical and chemical properties of the principal orchard soils in the Eastern Panhandle of West Virginia. West Virginia Agr. Exp. Sta. Bull. 303. 1942.
3. BUEHRER, T. F. and J. A. WILLIAMS. The hydrolysis of calcium carbonate and its relation to the alkalinity of calcareous soils. Arizona Agr. Exp. Sta. Tech. Bull. 64. 1936.
4. COLLISON, R. C., S. E. COLLISON and J. D. HARLAN. Some relationships between soil properties and performance of Baldwin and Greening apple trees. New York (Geneva) Agr. Exp. Sta. Tech. Bull. 194. 1932.
5. DOUGHTY, J. L. The advantages of a soil paste for routine pH determination. Sci. Agr. 22 : 135-138. 1941.
6. GARDNER, V. R., F. C. BRADFORD and H. D. HOOKER, JR. The fundamentals of fruit production. McGraw-Hill Book Co., New York. 1939.
7. HEINICKE, A. J. and L. P. BATJER. Difference in soil and tree growth within limited areas. Proc. Amer. Soc. Hort. Sci. 27 : 69-74. 1930.
8. LOUGHRIDGE, R. H. Tolerance of alkali by various cultures. California Agr. Exp. Sta. Bull. 133. 1901.
9. MAGNESS, J. R. Establishing and managing young apple orchards. U.S. Dept. Agr. Farm. Bull. 1897. 1942.
10. MAGNESS, J. R., E. S. DEGMAN and J. R. FURR. Soil moisture and irrigation investigations in Eastern apple orchards. U.S. Dept. Agr. Tech. Bull. 491. 1935.
11. MCGEORGE, W. T. Factors contributing to the reaction of soils and their pH measurement. Arizona Agr. Exp. Sta. Tech. Bull. 78. 1938.
12. MORGAN, M. F. A suggested table of pH requirements for New England crops on mineral soils. (Mimeographed). 1937.
13. MORGAN, M. F., J. H. GOURLEY and J. K. ALBEITER. The soil requirements of economic plants. In "Soils and Men," pp. 753-776. U.S. Dept. Agr. Yearbook of Agriculture. 1938.
14. OSKAMP, J. Ground water as a measure of the suitability of a soil for orchard purposes. Proc. Amer. Soc. Hort. Sci. 30 : 410-414. 1933.
15. OSKAMP, J. Soils in relation to fruit growing in New York. VI. Tree behavior on important soil profiles in the Williamson-Marion area, Wayne County. New York (Cornell) Agr. Exp. Sta. Bull. 626. 1935.
16. OSKAMP, J. Soils in relation to fruit growing in New York. IX. Tree behavior on important soil profiles in the Newfane-Olcott area, Niagara County. New York (Cornell) Agr. Exp. Sta. Bull. 653. 1936.
17. OSKAMP, J. and L. P. BATJER. Soils in relation to fruit growing in New York. II. Size, production, and rooting habit of apple trees on different soil types in the Hilton and Morton areas, Monroe County. New York (Cornell) Agr. Exp. Sta. Bull. 550. 1932.
18. OSKAMP, J. and L. P. BATJER. Soil acidity and orchard production. Proc. Amer. Soc. Hort. Sci. 29 : 188-192. 1932.
19. PARTRIDGE, N. L. and J. O. VEATCH. The influence of various phases of Bellefontaine fine sandy loam and Washtenaw silt loam on the growth of apple trees. Proc. Amer. Soc. Hort. Sci. 33 : 124-130. 1935.
20. PARTRIDGE, N. L. and J. O. VEATCH. Selection of orchard sites in southern Michigan. Michigan Agr. Exp. Sta. Circ. Bull. 155. 1936.
21. SPURWAY, C. H. Soil reaction (pH) preferences of plants. Michigan Agr. Exp. Sta. Spec. Bull. 306. 1941.
22. SWEET, A. T. Soils of Orleans County, New York, in their relation to orchard planting. New York (Cornell) Agr. Exp. Sta. Bull. 637. 1935.
23. VEATCH, J. O. and N. L. PARTRIDGE. Response of fruit tree growth to the soil complex reached by the roots. Proc. Amer. Soc. Hort. Sci. 29 : 208-212. 1932.
24. VEATCH, J. O. and N. L. PARTRIDGE. Utilization of land types for fruit production, Berrien County, Michigan. Michigan Agr. Exp. Sta. Spec. Bull. 257. 1934.
25. WILCOX, J. C. Some factors affecting apple production in the Okanagan Valley. I. Tree size, tree vigour, biennial bearing, and distance of planting. Sci. Agr. 25 : 189-213. 1945.
26. WILCOX, J. C. and R. H. SPILSBURY. Soil moisture studies. II. Some relationships between moisture measurements and mechanical analysis. Sci. Agr. 21 : 459-472. 1941.
27. WILCOX, J. C. and R. H. SPILSBURY. Soil moisture studies. III. An application of soil moisture measurements to soils classification. Sci. Agr. 21 : 473-478. 1941.
28. WILDER, H. J. Soils of Massachusetts and Connecticut with special reference to apples and peaches. U.S. Dept. Agr. Bull. 140. 1915.

APPENDIX

TABLE 3.—MCINTOSH PLOT TREE DATA

(Plot averages)

1	2	3	4	5	6	7
Plot No.	No. of trees	Trunk-ground ratio	Terminal length	Biennial bearing index	Total yield*	Profitable yield*
			cm.		boxes	boxes
P2†	5	.27	28.1	70	1227	1111
P3	5	.29	29.1	66	1079	1058
P4	5	.29	28.0	66	1051	977
P1	3	.27	28.9	69	987	891
P9	5	.37	28.4	38	1813	1525
P10	1	.33	32.3	35	1950	1531
P5	5	.49	38.7	19	1477	942
P7	3	.39	25.9	56	1123	936
P6	4	.37	26.7	48	1007	912
S12	5	.32	19.3	93	768	687
S10	5	.38	26.2	61	716	671
T2	4	.48	28.2	100	1001	842
T3	4	.43	32.4	85	1235	1084
T6	5	.26	29.1	96	1328	1131
T7	5	.26	29.8	83	1334	1110
T8	5	.40	28.7	25	1435	1242
T9	1	.34	22.6	58	1264	1165
K2	4	.31	16.4	26	1339	1230
K6	3	.25	22.7	24	1413	1246
K21	5	.31	21.1	65	1135	1011
K7	5	.32	26.0	57	1080	978
K9	5	.37	21.0	76	924	861
K27	5	.36	16.2	76	781	739
K16	5	.33	24.4	67	1174	1082
K10	4	.34	22.9	37	1153	1066
K54	5	.33	26.1	16	1420	1110
K11	3	.22	27.2	47	1254	998
K12	5	.28	25.4	42	1349	1144
K13	5	.29	25.8	52	1326	1158
K14	5	.26	25.2	51	1282	1103
K15	3	.25	24.7	47	914	772
K46	3	.26	28.1	47	1139	928
K51	3	.31	26.7	61	1083	893
K22	5	.28	27.7	67	1321	1206
K25	5	.38	28.2	37	1534	1342
K24	3	.37	25.5	56	1509	1360
K49	4	.28	30.4	38	1350	1013
K8	5	.32	22.0	32	1660	1433
K48	5	.26	30.5	56	1406	1157
B29	5	.25	22.8	45	1080	977
B30	5	.27	32.4	59	1170	978
B31	4	.27	23.5	45	1165	1031
B1	5	.37	22.5	64	1092	935
B34	5	.39	25.9	83	1070	929
B33	5	.37	19.7	48	1413	1307
B38	5	.42	19.2	57	1159	1084
B36	5	.40	26.1	87	880	844
B37	5	.36	28.0	72	896	838
G42	5	.31	25.7	23	1602	1328
G50	5	.42	26.6	71	858	849
G26	5	.33	24.4	15	1576	1313

* The total and profitable yield are expressed in terms of loose bushel boxes per acre, adjusted for differences in size of tree.

† The arrangement of the plot numbers is by position in the field, rather than by number.

APPENDIX

TABLE 3.—MCINTOSH PLOT TREE DATA—*Continued*

(Plot averages)

1	2	3	4	5	6	7
Plot No.	No. of trees	Trunk-ground ratio	Terminal length	Biennial bearing index	Total yield*	Profitable yield*
			cm.		boxes	boxes
G18	5	.38	25.7	61	1032	768
G17	5	.29	19.6	76	978	880
G19	5	.34	22.1	31	1144	1023
G20	5	.30	20.2	28	1216	1147
W2	5	.32	19.5	26	1060	953
W7	5	.29	28.0	16	996	822
W6	5	.29	23.8	47	909	852
W5	5	.31	18.4	28	1261	1030
W9	5	.37	29.5	19	1583	1224
W8	5	.34	27.0	12	1486	1213
W10	4	.48	25.4	30	1391	1222
O14	5	.32	23.1	20	1274	1134
O17	5	.34	25.1	72	1000	896
O15	5	.25	33.4	28	1181	966
O19	5	.36	14.6	57	927	768

* The total and profitable yield are expressed in terms of loose bushel boxes per acre, adjusted for differences in size of tree.

† The arrangement of the plot numbers is by position in the field, rather than by number.

TABLE 4.—MCINTOSH PLOT SOILS DATA

1	2	3	4	5	6	7
Plot No.	Soil depth	Gravel content*	M.C.F.†	M.C.F. × depth	pH	Lime content
	inches	%	inches	inches		%
P2	0-8	0.0	3.58	2.38	6.85	0.0
	8-24	0.0	3.48	4.64	7.88	2.1
	24-60	0.0	3.43	10.29	8.08	5.2
	0-60			17.31‡	7.60‡	
P3	0-8	0.0	3.63	2.52	6.28	0.0
	8-24	0.0	3.32	4.43	7.47	0.1
	24-60	0.0	3.03	9.09	8.13	3.9
	0-60			16.04	7.29	
P4	0-8	0.0	3.52	2.34	6.36	0.0
	8-24	0.0	3.31	4.41	7.75	0.6
	24-60	0.0	3.43	10.29	8.13	5.4
	0-60			17.04	7.41	

* The M.C.F. and lime content have been adjusted for the per cent gravel.

† M.C.F. = moisture holding capacity, expressed as inches of water per foot of soil.

M.C.F. × depth = moisture capacity multiplied by depth in feet, to give the inches of water held in each unit of the profile.

‡ Total of M.C.F. × depth and average of profile pH. The average pH is unweighted.

TABLE 4.—MCINTOSH PLOT SOILS DATA—*Continued*

1	2	3	4	5	6	7
Plot No.	Soil depth	Gravel content*	M.C.F.†	M.C.F. × depth	pH	Lime content
	inches	%	inches	inches		%
P1	0-8	0.0	3.59	2.39	7.61	1.4
	8-24	0.0	3.43	4.57	8.19	5.2
	24-60	0.0	3.10	9.30	8.29	2.8
	0-60			16.26	8.03	
P9	0-8	0.0	3.22	2.15	7.13	0.0
	8-24	0.0	3.32	4.43	7.89	0.1
	24-60	0.0	3.69	11.07	8.19	4.9
	0-8			17.65	7.74	
P10	0-8	0.0	2.96	1.97	7.40	0.0
	8-24	0.0	2.83	3.87	7.79	0.0
	24-60	0.0	3.50	10.50	8.14	4.5
	0-60			16.34	7.78	
P5	0-8	0.0	3.45	2.30	6.67	0.0
	8-24	0.0	3.28	4.37	7.93	1.6
	24-60	0.0	3.05	9.15	8.33	3.0
	0-60			15.82	7.64	
P7	0-8	21.9	2.50	1.67	6.68	0.0
	8-24	0.0	2.85	3.67	6.73	0.0
	0-24			5.34	6.70	
P6	0-8	0.0	3.37	2.25	6.68	0.0
	8-24	29.4	1.98	2.64	6.35	0.0
	0-24			4.89	6.51	
S12	0-8	0.0	2.96	1.97	6.93	0.0
	8-24	33.7	1.66	2.21	8.09	0.1
	0-24			4.18	7.51	
S10	0-8	18.0	2.24	1.49	6.78	0.0
	8-24	40.1	1.42	1.89	6.64	0.0
	0-24			3.38	6.71	
T2	0-8	8.0	2.94	1.96	6.11	0.1
	8-36	19.4	2.55	5.95	8.06	3.3
	0-36			7.91	7.08	
T3	0-8	7.9	2.53	1.69	6.15	0.0
	8-24	38.4	1.52	2.03	7.31	0.0
	0-24			3.72	6.73	
T6	0-8	20.2	2.65	1.77	7.64	0.0
	8-24	35.6	1.77	2.36	7.48	0.0
	0-24			4.13	7.56	
T7	0-8	33.6	2.19	1.46	7.39	0.0
	8-24	57.4	1.21	1.61	7.28	0.0
	0-24			3.07	7.33	
T8	0-8	4.3	3.10	2.07	7.27	0.0
	8-30	28.2	2.27	4.16	7.86	0.6
	0-30			6.23	7.56	

* The M.C.F. and lime content have been adjusted for the per cent gravel.

† M.C.F. = moisture holding capacity, expressed as inches of water per foot of soil.

‡ M.C.F. × depth = moisture capacity multiplied by depth in feet, to give the inches of water held in each unit of the profile.

§ Total of M.C.F. × depth and average of profile pH. The average pH is unweighted.

TABLE 4.—MCINTOSH PLOT SOILS DATA—*Continued*

1	2	3	4	5	6	7
Plot No.	Soil depth	Gravel content*	M.C.F.†	M.C.F. × depth	pH	Lime content
	inches	%	inches	inches		%
T9	0- 8	2.2	2.44	1.63	7.22	0.0
	8-24	18.5	1.86	2.48	7.29	0.0
	0-24			4.11	7.25	
K2	0- 8	0.0	2.87	1.91	6.10	0.0
	8-20	26.7	1.95	1.95	6.57	0.0
	0-20			3.86	6.33	
K6	0- 8	0.0	3.00	2.00	6.35	0.0
	8-18	36.8	1.58	1.32	6.77	0.0
	0-18			3.32	6.56	
K21	0- 8	0.0	2.73	1.82	6.75	0.0
	8-26	0.0	2.54	3.81	6.74	0.0
	0-26			5.63	6.74	
K7	0- 8	0.0	2.96	1.97	6.27	0.0
	8-24	0.0	2.85	3.80	6.67	0.0
	24-44	0.0	2.95	4.91	7.84	0.5
	0-44			10.68	6.93	
K9	0- 8	0.0	3.08	2.06	6.06	0.0
	8-24	4.1	2.75	3.67	6.90	0.0
	24-35	13.0	2.65	2.43	8.34	0.9
	0-35			8.16	7.10	
K27	0- 8	0.0	3.35	2.23	6.61	0.0
	8-40	61.7	0.95	2.25	6.66	0.0
	0-40			4.45	6.63	
K16	0- 8	0.0	3.22	2.14	6.70	0.0
	8-24	0.0	3.20	4.27	6.96	0.0
	24-54	0.0	3.73	9.34	7.98	3.0
	0-54			15.75	7.21	
K10	0- 8	8.7	2.76	1.84	6.73	0.0
	8-27	54.7	1.16	1.84	6.49	0.0
	0-27			3.68	6.61	
K39	0- 8	62.5	1.23	0.82	6.56	0.0
	8-29	51.1	1.25	2.19	6.30	0.0
	0-29			3.01	6.43	
K53	0- 8	32.8	2.44	1.63	6.04	0.0
	8-28	62.3	1.09	1.82	5.98	0.0
	0-28			3.45	6.01	
K54	0- 8	9.2	2.86	1.91	6.40	0.0
	8-25	64.0	0.94	1.33	6.36	0.0
	0-25			3.24	6.38	
K11	0- 8	12.8	2.89	1.93	6.46	0.0
	8-22	59.4	1.01	1.18	6.36	0.0
	0-22			3.11	6.41	

* The M.C.F. and lime content have been adjusted for the per cent gravel.

† M.C.F. = moisture holding capacity, expressed as inches of water per foot of soil.

M.C.F. × depth = moisture capacity multiplied by depth in feet, to give the inches of water held in each unit of the profile.

‡ Total of M.C.F. × depth and average of profile pH. The average pH is unweighted.

TABLE 4.—McINTOSH PLOT SOILS DATA—*Continued*

1	2	3	4	5	6	7
Plot No.	Soil depth	Gravel content*	M.C.F.†	M.C.F. × depth	pH	Lime content
	inches	%	inches	inches		%
K12	0- 8	12.0	2.74	1.83	5.87	0.0
	8-23	53.8	1.12	1.40	6.34	0.0
	0-23			3.23	6.10	
K13	0- 8	11.8	2.84	1.89	6.30	0.0
	8-25	46.4	1.26	1.78	6.34	0.0
	0-25			3.67	6.32	
K14	0- 8	11.0	2.78	1.85	5.99	0.0
	8-24	47.4	1.25	1.67	6.36	0.0
	0-24			3.52	6.17	
K15	0- 8	27.2	2.40	1.60	6.66	0.0
	8-23	58.0	1.07	1.34	6.46	0.0
	0-23			2.94	6.56	
K46	0- 8	9.4	2.74	1.83	6.27	0.0
	8-22	46.4	1.29	1.50	6.51	0.0
	0-22			3.33	6.39	
K51	0- 8	9.9	2.79	1.86	5.67	0.0
	8-21	45.1	1.32	1.43	6.15	0.0
	0-21			3.29	5.91	
K17	0- 8	0.0	3.50	2.33	6.64	0.6
	8-24	0.0	3.73	4.97	6.54	0.0
	24-48	0.0	4.12	8.14	7.80	2.6
	0-48			15.44	6.99	
K18	0- 8	0.0	4.18	2.78	6.72	0.0
	8-24	0.0	4.45	5.94	7.74	2.7
	24-60	0.0	4.22	12.66	8.23	3.3
	0-60			21.38	7.56	
K22	0- 8	13.2	2.65	1.77	5.83	0.0
	8-22	50.4	1.60	1.87	6.14	0.0
	0-22			3.64	5.98	
K44	0- 8	14.0	2.86	1.91	5.78	0.0
	8-22	63.2	0.97	1.13	6.10	0.0
	0-22			3.04	5.94	
K25	0- 8	0.0	4.08	2.72	6.53	0.0
	8-24	0.0	4.58	6.10	7.35	1.4
	24-60	0.0	4.58	13.64	7.78	2.3
	0-60			22.46	7.22	
K24	0- 8	0.0	2.78	1.85	6.54	0.0
	8-24	19.3	1.97	2.62	6.64	0.0
	24-57	16.1	2.58	7.09	8.02	0.7
	0-57			11.56	7.07	

* The M.C.F. and lime content have been adjusted for the per cent gravel.

† M.C.F. = moisture holding capacity, expressed as inches of water per foot of soil.

M.C.F. × depth = moisture capacity multiplied by depth in feet, to give the inches of water held in each unit of the profile.

‡ Total of M.C.F. × depth and average of profile pH. The average pH is unweighted.

TABLE 4.—MCINTOSH PLOT SOILS DATA—*Continued*

1	2	3	4	5	6	7
Plot No.	Soil depth	Gravel content*	M.C.F.†	M.C.F. × depth	pH	Lime content
	inches	%	inches	inches		%
K49	0- 8	0.0	4.32	2.88	6.69	0.0
	8-24	0.0	4.62	6.16	7.95	3.6
	24-60	0.0	4.67	14.01	7.63	2.0
	0-60			23.05	7.42	
K8	0- 8	0.0	3.84	2.56	7.02	0.0
	8-24	0.0	4.00	5.44	7.64	2.5
	24-60	0.0	4.22	12.66	7.96	2.2
	0-60			20.66	7.54	
K48	0- 8	0.0	4.26	2.84	6.63	0.0
	8-24	0.0	4.35	5.91	7.65	1.7
	24-60	0.0	4.35	13.05	8.22	3.2
	0-60			21.80	7.50	
B29	0- 8	0.0	2.85	1.90	6.93	0.0
	8-30	0.0	2.60	4.76	7.10	0.0
	0-30			6.66	7.01	
B30	0- 8	0.0	2.92	1.95	6.21	0.0
	8-27	0.0	2.68	4.25	6.68	0.0
	0-27			6.20	6.44	
B31	0- 8	0.0	2.92	1.95	5.82	0.0
	8-27	0.0	2.70	4.28	6.78	0.0
	0-27			6.23	6.30	
B1	0- 8	0.0	3.05	2.04	6.21	0.0
	8-24	0.0	2.88	3.92	6.69	0.0
	24-57	0.0	3.23	8.88	8.01	0.9
	0-57			14.84	6.97	
B34	0- 8	5.3	2.58	1.72	6.47	0.0
	8-24	7.1	2.65	3.60	6.58	0.0
	24-38	43.0	1.34	1.56	6.65	0.0
	0-38			6.88	6.57	
B33	0- 8	0.0	2.70	1.80	6.60	0.0
	8-24	0.0	2.65	3.60	6.44	0.0
	24-36	0.0	2.38	2.38	6.92	0.0
	0-36			7.78	6.66	
B38	0- 8	0.0	2.98	1.99	6.56	0.0
	8-27	0.0	2.60	4.11	6.32	0.0
	0-27			6.10	6.44	
B36	0- 8	0.0	3.02	2.01	6.02	0.0
	8-31	37.4	1.67	3.20	7.19	0.0
	0-31			5.21	6.60	
B37	0- 8	0.0	3.12	2.08	6.12	0.0
	8-27	31.1	1.88	2.98	6.62	0.0
	0-27			5.06	6.37	

* The M.C.F. and lime content have been adjusted for the per cent gravel.

† M.C.F. = moisture holding capacity, expressed as inches of water per foot of soil.

M.C.F. × depth = moisture capacity multiplied by depth in feet, to give the inches of water held in each unit of the profile.

‡ Total of M.C.F. × depth and average of profile pH. The average pH is unweighted.

TABLE 4.—MCINTOSH PLOT SOILS DATA—*Continued*

1	2	3	4	5	6	7
Plot No.	Soil depth	Gravel content*	M.C.F.†	M.C.F. × depth	pH	Lime content
	inches	%	inches	inches		%
G42	0- 8	0.0	3.27	2.18	6.95	0.0
	8-24	0.0	3.03	4.12	6.63	0.0
	24-60	0.0	2.73	8.19	8.18	1.4
	0-60			14.49	7.25	
G50	0- 8	0.0	2.76	1.84	5.95	0.0
	8-24	0.0	2.38	3.24	6.91	0.0
	24-60	0.0	2.70	8.10	8.24	0.3
	0-60			13.18	7.03	
G26	0- 8	0.0	2.92	1.95	6.94	0.0
	8-24	0.0	2.82	3.70	8.12	0.1
	24-60	0.0	2.73	8.19	8.23	0.2
	0-60			13.84	7.76	
G18	0- 8	9.9	2.37	1.58	6.36	0.0
	8-24	18.9	2.03	2.76	6.79	0.0
	24-44	22.5	2.32	3.87	7.73	0.1
	0-44			8.21	6.96	
G17	0- 8	40.0	2.06	1.37	7.02	0.0
	8-24	42.2	1.66	2.26	7.31	0.0
	24-40	24.8	2.56	3.41	8.21	1.5
	0-40			7.04	7.51	
G19	0- 8	0.0	4.10	2.73	7.12	0.0
	8-24	0.0	3.67	4.99	7.60	1.0
	24-57	0.0	3.46	9.52	8.12	6.2
	0-57			17.24	7.61	
G20	0- 8	0.0	4.08	2.72	7.15	0.0
	8-24	0.0	4.20	5.71	7.68	2.7
	24-60	0.0	4.20	12.60	7.92	4.0
	0-60			21.03	7.58	
W2	0- 8	0.0	3.82	2.54	6.56	0.0
	8-24	0.0	4.10	5.58	7.25	0.0
	24-48	0.0	3.68	7.36	7.93	0.9
	0-48			15.48	7.25	
W7	0- 8	0.0	2.38	1.59	6.11	0.0
	8-30	5.2	2.26	4.15	6.64	0.0
	0-30			5.74	6.37	
W6	0- 8	8.5	2.26	1.51	6.45	0.0
	8-24	26.1	1.77	2.41	6.50	0.0
	0-24			3.92	6.47	
W5	0- 8	3.5	2.54	1.69	6.50	0.0
	8-24	20.0	1.88	2.56	6.80	0.0
	0-24			4.25	6.65	

* The M.C.F. and lime content have been adjusted for the per cent gravel.

† M.C.F. = moisture holding capacity, expressed as inches of water per foot of soil.

M.C.F. × depth = moisture capacity multiplied by depth in feet, to give the inches of water held in each unit of the profile.

‡ Total of M.C.F. × depth and average of profile pH. The average pH is unweighted.

TABLE 4.—MCINTOSH PLOT SOILS DATA—*Concluded*

1	2	3	4	5	6	7
Plot No.	Soil depth	Gravel content*	M.C.F.†	M.C.F. × depth	pH	Lime content
	inches	%	inches	inches		%
W4	0- 8	0.0	2.53	1.69	6.13	0.0
	8-24	0.0	2.48	3.37	6.62	0.0
	24-60	3.1	2.13	6.39	6.95	0.0
	0-60			11.45	6.57	
W9	0- 8	0.0	3.92	2.61	6.63	0.0
	8-24	0.0	4.12	5.60	6.80	0.0
	24-60	0.0	4.05	12.15	8.01	3.2
	0-60			20.36	7.15	
W8	0- 8	0.0	2.82	1.88	6.50	0.0
	8-24	10.4	2.46	3.35	6.81	0.0
	24-52	0.0	3.83	8.94	8.27	2.5
	0-52			14.17	7.19	
W10	0- 8	0.0	3.18	2.12	6.57	0.0
	8-24	0.0	2.68	3.64	6.42	0.0
	24-60	0.0	3.20	9.60	8.24	0.0
	0-60			15.36	7.08	
O14	0- 8	0.0	3.28	2.18	6.63	0.0
	8-33	8.0	2.65	5.52	7.79	0.0
	0-33			7.70	7.21	
O17	0- 8	6.8	2.73	1.82	6.44	0.0
	8-24	8.9	2.41	3.28	6.57	0.0
	0-24			5.10	6.50	
O15	0- 8	37.9	1.58	1.05	6.33	0.0
	8-24	30.4	1.76	2.40	6.20	0.0
	0-24			3.45	6.26	
O18	0- 8	27.3	1.93	1.29	7.01	0.0
	8-24	40.5	1.70	2.31	7.15	0.0
	0-24			3.60	7.08	
O19	0- 8	43.8	2.19	1.46	7.42	0.0
	8-24	53.3	1.33	1.81	7.40	0.1
	0-24			3.26	7.41	

* The M.C.F. and lime content have been adjusted for the per cent gravel.

† M.C.F. = moisture holding capacity, expressed as inches of water per foot of soil.

M.C.F. × depth = moisture capacity multiplied by depth in feet, to give the inches of water held in each unit of the profile.

‡ Total of M.C.F. × depth and average of profile pH. The average pH is unweighted.

SOME FACTORS AFFECTING APPLE YIELDS IN THE OKANAGAN VALLEY

III. ROOT DISTRIBUTION¹

J. C. WILCOX² AND A. T. KNIGHT³

Dominion Experimental Station, Summerland, B.C.

[Received for publication June 2, 1945]

This paper is the third in a series reporting the findings of an investigation into the effects of certain factors on apple tree performance in the Okanagan Valley in British Columbia. The first paper (21) dealt with tree size, tree vigour, biennial bearing and distance of planting; and the second paper (22) dealt with soil depth, moisture holding capacity and pH. This present paper reports findings with respect to root distribution, and its relationship to certain soil characteristics and soil treatments on the one hand and to tree performance on the other hand.

The findings from three separate studies are combined in this report: (a) Studies of root distribution as affected by soil texture and depth and by certain cultural treatments, made in 1933. (b) Similar studies made in 1936. Most of the work in 1933 and 1936 was done in the Dominion Experimental Substation orchard at Kelowna. (c) Studies of root distribution in the McIntosh plots used as the general basis for this series of papers. These studies were made in 1939 and 1940.

Comprehensive reviews of the literature on the root growth of fruit trees have already been published (3, 12, 24), and it does not appear necessary to present a further review at this time.

PROCEDURE

In the 1933 studies, trenches were dug beside selected trees in a series of plots receiving differential irrigation, fertilizer, and root-pruning treatments, and beside trees in soil differing in depth and texture, to a total of 25 trenches. The procedure used in each case was to dig a trench 2 feet wide starting at a point 5 feet from the trunk of a mature tree, and proceeding outward to the centre of one of the surrounding tree squares, usually a distance of 16 feet. In most cases, digging was discontinued when the roots petered out; but in no case was a trench dug deeper than 8 feet, even though some roots were still in evidence at that depth. The walls of the trench were smoothed down with the shovel, scarified lightly with a rake to reveal the root tips, and divided into foot squares with string and nails. The soil variations were mapped, on the basis of visual examination only, and designated as horizons A, B and C in the usual way (9). The apple roots exposed were also mapped, in accordance with the following diameter classes: (1) less than $\frac{1}{8}$ inch, (2) $\frac{1}{8}$ to $\frac{1}{4}$ inch, (3) $\frac{1}{4}$ to $\frac{1}{2}$ inch, (4) $\frac{1}{2}$ to 1 inch, (5) over 1 inch.

In 1936, 12 trenches were dug beside trees in some of the same plots as in 1933. The procedure was similar, except that digging was started at 3 feet from the trunk.

¹ Contribution No. 654 from the Division of Horticulture, Experimental Farms Service, Dominion Department of Agriculture, Ottawa, Canada.

² Assistant Superintendent in charge of nutritional investigations with tree fruits.

³ Formerly Graduate Assistant at the Dominion Experimental Station at Summerland, now with the Ford Motor Company at Windsor, Ontario.

In 1939 and 1940, 13 trenches were dug in the irrigation and fertilizer plots on the Substation at Kelowna, and 50 trenches were dug beside mature trees in the McIntosh plots (21) in grower owned orchards. The procedure used was to start 5 feet from the trunk and dig outward just far enough to map a 4-foot length along the side of the trench. The 2-foot face nearest the tree and one or both side walls of the trench were divided into 6-inch squares with string, and the soil horizons and root distribution were mapped, as in 1933. (The area covered is illustrated in Figure 6).

As noted in a previous paper (21), groups of mature McIntosh trees were selected in grower owned orchards in the Okanagan Valley in 1937, with 5 trees or less to a group. For want of a better term, the orchard area containing each group of trees was called a "plot." In selecting these plots, a deliberate attempt was made to include a wide variation in soil texture, soil depth, and cultural treatments. The relationships of soil texture and depth to tree performance in 75 of the plots have already been reported (22). It was in these plots that the 50 trenches beside mature McIntosh trees were dug in 1939 and 1940. They were located as follows: 26 in East Kelowna, 9 in Rutland, 2 in Glenmore, 8 in Winfield, and 5 in Oyama.

Although there was a wide variation among plots in soil depth and texture, within any one plot the soil was almost always reasonably uniform. The degree of uniformity within each plot was determined prior to excavating the trench, by making auger borings around each tree, and the location finally selected for the trench was always one that appeared to represent both the tree and the plot fairly. Because of this, it was felt that the root counts could reasonably be compared not only with the records on the tree adjacent to the trench, but also with the averages of all trees in the plot.

In the first paper of this series (21), the methods of obtaining the tree records in the McIntosh plots and of conducting the statistical analyses on them were described. For the purpose of correlating with soil characteristics, the tree data were tabulated as plot averages in the second paper (22) of the series. These same plot averages are used in this paper for comparison with root distribution. In the second paper, also, the procedures used in sampling the soil and in making certain chemical and physical analyses were described, and the data thus obtained were presented. These data are likewise used in this paper for comparison with root distribution data. Reference is made under "Results" to soil analyses for phosphorus and potassium. These analyses will be reported in detail in a subsequent paper.

In order to study the relationships of root distribution to soil characteristics and to tree performance, it was considered desirable to express the root distribution in mathematical form. As a basis for this expression, the smaller or "feeding" roots were considered to be the most suitable. Accordingly, all roots less than $\frac{1}{8}$ inch in diameter were counted from the profile maps, and were tabulated by depths and by distance from the tree. In calculating the totals per tree, only those roots were used that lay between the surface and 60 inches in depth, and in the 6 feet of pit face represented by 2 feet at the end nearest the tree and 4 feet from this end outward along one side wall of the trench. The results from the 50 McIntosh plots are presented in Table 3 in the Appendix. These results are used in all of the root correlations presented in this paper.

RESULTS

General Root Distribution

From point to point around a tree, the concentration of fibrous roots was found to be somewhat variable. For the most part, however, this variability did not appear great enough to invalidate the use of a single trench to represent the tree as a whole. Occasionally, quite wide variability in root concentration around a tree was encountered. In some cases it was obviously due to injury to large roots by the discs or furrower; in other cases it appeared to be associated with changes in soil depth and texture. Such trees were of course avoided in making trench studies of the roots.

In contrast with the comparative uniformity from point to point around the tree was the lack of uniformity in other directions. In many cases, there was considerable variability in concentration of fibrous roots with increasing depth in the soil and with increasing distance from the tree. This can be seen from Figures 5 and 6 and from the data in Table 3. The lack of uniformity was usually much less marked with older trees than with younger trees.

In spite of this lack of uniformity in root distribution, observation and counts revealed that root distribution was definitely affected by certain factors. In general, the older and the larger the tree, the greater was the concentration of fibrous roots farther out from the trunk and deeper down in the soil; and as a result, the greater was the total number of fibrous roots per tree. Although the trees in the McIntosh plots were all classed as "mature," there seemed to be some relationship among them between tree size and root concentration, as evidenced by the correlation shown in Table 1 between trunk circumference and root concentration in the 6- to 24-inch layer.

TABLE 1.—SOME CORRELATIONS BETWEEN ROOT CONCENTRATION AND OTHER FACTORS

Two factors correlated		Coefficient of correlation
Fibrous roots,*6-24 inches	Trunk circumference	+ .173 (NS)
Fibrous roots, 6-12 inches	Depth of soil	+ .010 (NS)§
Fibrous roots, 6-24 inches	M.H.C.,† 8-24 inches	+ .153 (NS)
Fibrous roots, 0-60 inches	M.H.C., 0-60 inches	+ .513 (HS)
Fibrous roots, 6-24 inches	pH, 8-24 inches	+ .295 (S)
Fibrous roots, 6-24 inches	pH, 8-24 inches‡	+ .254 (NS)
Fibrous roots, 6-24 inches	P content, 8-24 inches	+ .107 (NS)
Fibrous roots, 0-60 inches	P content, 0-60 inches	- .037 (NS)
Fibrous roots, 6-24 inches	K content, 8-24 inches	+ .169 (NS)
Fibrous roots, 0-60 inches	K content, 0-60 inches	+ .390 (HS)
Fibrous roots, 0-60 inches	K content, 0-60 inches‡	- .145 (NS)
Fibrous roots, 0-60 inches	Terminal length	+ .076 (NS)
Fibrous roots, 0-60 inches	Yield per acre	+ .127 (NS)
Fibrous roots, 6-24 inches	Yield per acre	+ .069 (NS)

* Fibrous roots = roots less than $\frac{1}{2}$ inch in diameter.

† M.H.C. = total moisture holding capacity per stated depth, expressed in inches of water.

‡ In these two correlations, the effects of the M.H.C. have been eliminated.

§ NS = non-significant, with odds less than 19 : 1.

S = significant, with odds between 19 : 1 and 99 : 1.

HS = highly significant, with odds greater than 99 : 1.

As would be expected, there was a tendency for the concentration of fibrous roots to decrease with greater distance from the trunk. This held true even within the 4-foot distance mapped in the McIntosh plots. When the percentages of fibrous roots at each distance were averaged for the 50 trenches, the results were as follows:

5 feet from trunk (average of two feet of pit face)	22.8%
5 to 6 feet from trunk	21.9%
6 to 7 feet from trunk	19.9%
7 to 8 feet from trunk	18.7%
8 to 9 feet from trunk	16.7%
	<hr/> 100.0%

The degree to which the roots were distributed in the surface horizon appeared to depend mostly on cover crop, cultivation, and irrigation practices. With sod grasses, the cover crop roots tended to exclude the apple roots from the top few inches. With leguminous cover crops, this effect was not so marked. Deep cultivation likewise reduced the number of roots in the surface horizon. The roots came closest to the surface under a cultural system involving frequent light cultivations (spring, midsummer and fall) and frequent irrigations. In some cases, the root concentration in the top foot appeared by visual examination to be greater where the solum (A plus B horizons) was shallower, but this was not borne out by a correlation between the soil depth and the number of fibrous roots in the 6- to 12-inch layers of the 50 plots (Table 1). In almost every case, the greatest concentration of fibrous roots was found between the depths of 6 and 24 inches. The largest roots were usually encountered between the depths of 6 and 18 inches.

The greatest depth of rooting depended primarily on the depth of the solum. In most of the plots the soil was underlain at depths of less than 5 feet by a mixture of clear sand and gravel or by clear sand alone.

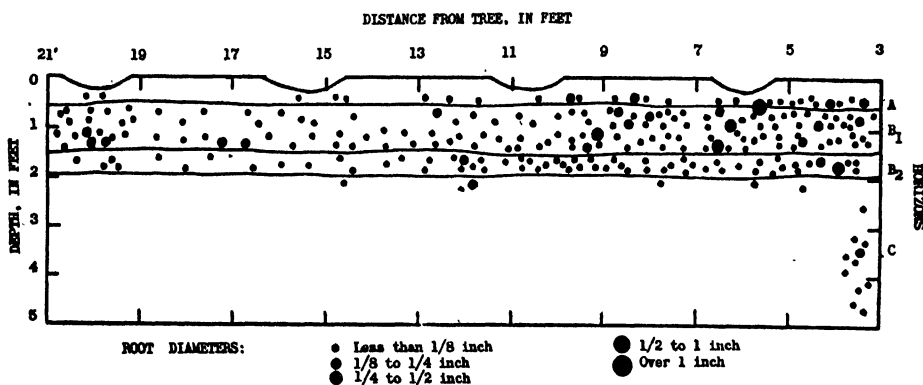


FIGURE 1. Root distribution along one wall of a pit 5 feet deep, dug radially 3 to 21 feet from tree C5 in the Substation orchard at Kelowna. The soil is a shallow phase of the Rutland sandy loam series (4), and is typical of many of the 50 McIntosh plots. It appears to be too shallow for maximum yields. The soil in the surface six inches was pretty well filled with grass roots. Some of the apple roots in the outer part of the pit were from neighbouring trees. These trees were about 21 years old. Each of the smallest dots in the chart represents five fibrous roots, the other dots one root apiece. The soil horizons are as follows: A—dark loamy sand, B₁—loamy sand, B₂—loamy sand and gravel, C—mixture of coarse sand, gravel and stones.

The roots penetrated this "parent" horizon in varying degree, the distance depending on a number of factors. For the most part, the penetration was not over 1 foot. Directly under the tree, however, the penetration was usually much greater than this; and wherever decaying pine roots descended into the subsoil, apple roots followed them down for some distance, often as far as 8 feet or more from the surface. In the deeper soils, the roots were found to grow down to depths of at least 8 feet at 3 feet from the trunk, and to lesser depths out farther from the trunk. With the older trees in deep soils, the whole soil mass was usually permeated with roots to a depth of at least 6 feet. It should be noted that in the original selection of the McIntosh plots, those areas in the Valley that were known to be subject to seepage conditions were avoided; hence no difficulty was encountered from excess water.



FIGURE 2. A pit face in Plot K54. This is a shallow phase of the Rutland sandy loam series (4). The C horizon of coarse sand, gravel and stones is typical of many of the orch ards in the Okanagan Valley.

Characteristic types of root distribution are illustrated in Figures 1 to 5. The distribution of the roots in shallow soils is shown in Figures 1 and 2. These are typical of a high percentage of the plots covered in this investigation. The general shape of the root system in a shallow soil can

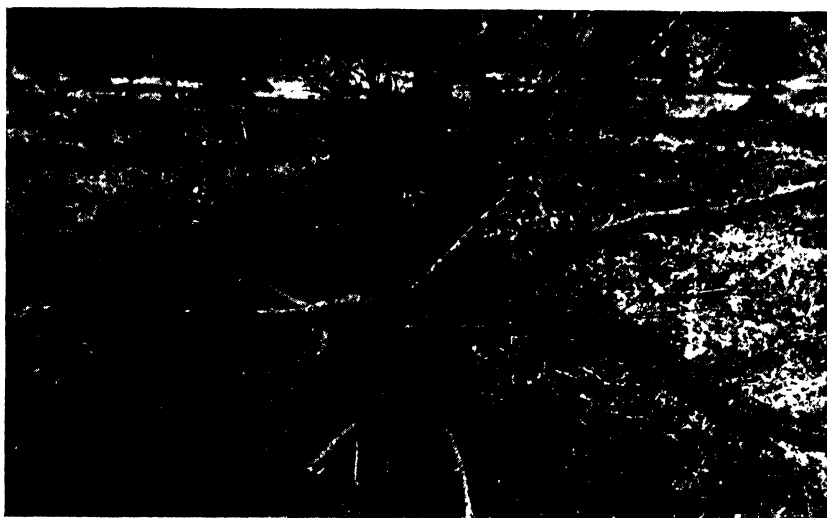


FIGURE 3. In a shallow soil, the roots of mature fruit trees tend to be shallow and spreading, with no evidence of a definite tap root.

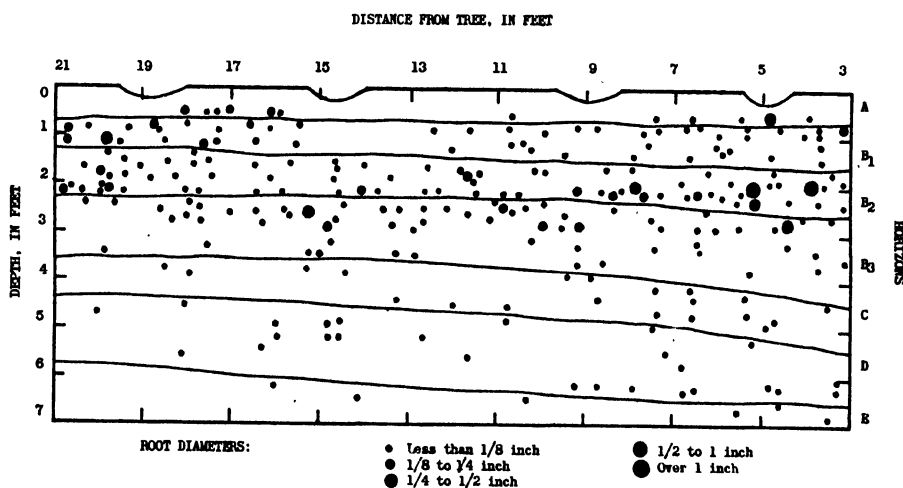


FIGURE 4. Root distribution along one wall of a pit 7 feet deep, dug radially 3 to 21 feet from tree BB23 in the Substation orchard at Kelowna. This tree is near the bottom of a hollow, and the soil is comparatively deep, well wetted, and well drained. The soil is a deep phase of the Rutland sandy loam series (4), and is well adapted to tree fruits. As indicated in the diagram, the pit was dug at right angles to the furrows. Some of the roots in the outer part were from neighbouring trees. The trees were about 21 years old. Each of the smallest dots in the chart represents five fibrous roots, and the other dots one root apiece. The soil horizons are as follows: A—dark loamy sand, B₁—dark sandy loam, B₂—medium sand, B₃—medium sand with dark concretions, C—medium to fine sand, D—silty loam, E—coarse sand.

also be seen in Figure 3. In no case has there been any evidence of a distinct tap root. The distribution of the roots in a deep, sandy loam soil is illustrated in Figure 4, and that in a deep, heavy soil in Figure 5.

Effects of Certain Soil Characteristics

A closer relationship was found between soil texture and root concentration within the one profile than between profiles. In most of the plots, where the soil tended to be sandy, those horizons containing the greater amounts of colloid usually contained the greater concentrations of fibrous roots. Where the soil was heavy, an intervening sandy horizon usually contained fewer roots. An example of this is shown in Figure 6. On the other hand, in the deep, heavy soils studied, occasional narrow horizons were encountered consisting of a tightly packed, laminated mixture high in clay and containing only a few roots (Figure 5). In only two cases was this laminated layer found to be of sufficient thickness to prevent the passage of roots. This was the closest approach to a "claypan" condition that was encountered.

To determine the relationship of soil texture to root concentration between profiles, the number of fibrous roots in the 6- to 24-inch layers of the 50 McIntosh plots was correlated with the moisture holding capacity of the 8- to 24-inch layers. The coefficient of correlation (+ 0.153, Table 1) was non-significant, but still indicated the possibility of greater root concentrations in the heavier soils. Observation indicated that when

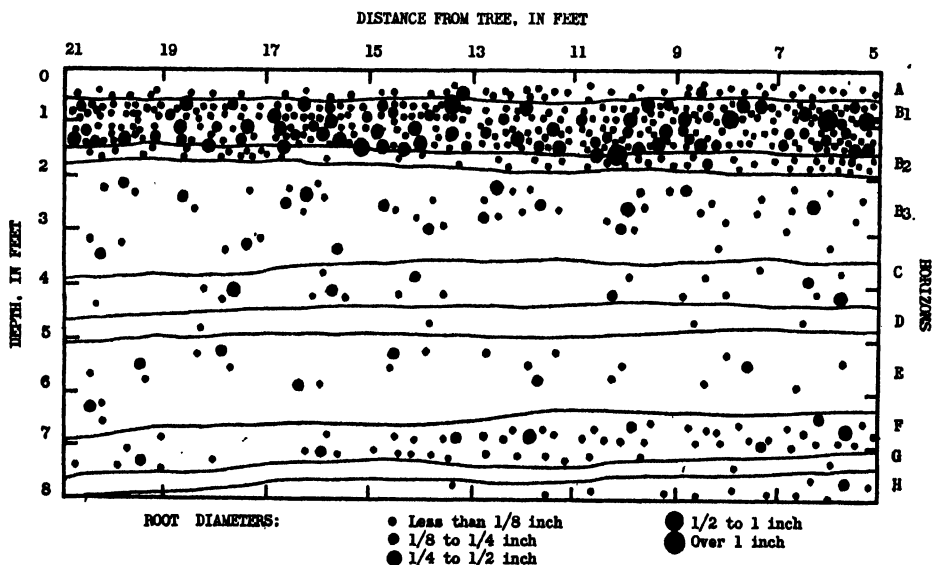


FIGURE 5.—Root distribution along one wall of a pit 8 feet deep, dug radially 5 to 21 feet from a tree in Plot K18. The soil is a deep phase of the Glenmore clay series (4). Where not subject to excess seepage, this soil is well adapted to tree fruits. The trees in this plot were about 40 years old. Each of the smallest dots in the chart represents five fibrous roots, the other dots one root apiece. The soil horizons are as follows: A—dark clay loam, B₁—friable clay loam, B₂—lumpy clay loam, B₃—clay loam mixed with sand, gravel, stones and lime, C—clay loam with some lime, D—dark laminated clay, E—uniform clay loam, F—silt loam and lime, quite friable, G—laminated clay, H—clay loam.

other things were equal, the greatest concentration of fibrous roots at any one depth could be expected in a soil moderately heavy in texture, but containing sufficient sand for reasonably good permeability. When the soil texture and soil depth were both taken into account, by correlating the total number of fibrous roots per profile with the total moisture holding capacity, the result was positive and highly significant ($+0.513$). In other words, there was a strong tendency for a larger total number of fibrous roots to be present in the heavy, deep soils than in the light, shallow soils.

No adverse effect of lime in the B horizon was noted on root concentration. In fact, in the deeper horizons of the heavier soils, visual examination indicated the root concentration to be greatest in those horizons rich in free carbonate (Figure 5).

To determine the effect of pH on root concentration, the number of fibrous roots in the 6- to 24-inch layer of the McIntosh plots was correlated with the pH of the 8- to 24-inch layer (22). The coefficient was significant ($+0.295$). As noted in the second paper (22) of this series, however, a positive relationship was found between the pH and the moisture holding capacity. When the effects of variations in moisture holding capacity were eliminated, the coefficient was reduced to $+0.254$. This is not far

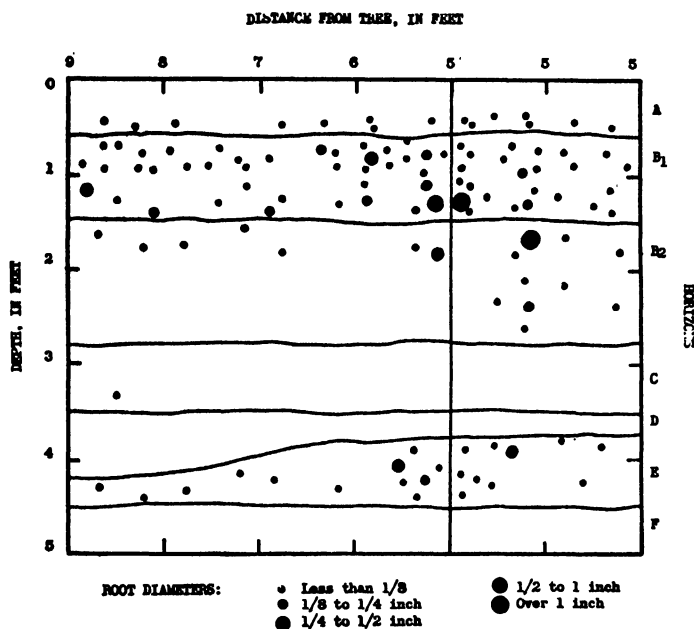


FIGURE 6. Root distribution along one end wall and one side wall of a pit 5 feet deep and 4 feet long, beside a tree in Plot K24. The soil is a shallow phase of the Glenmore clay series (4). This chart illustrates the procedure used in mapping the roots in the 50 McIntosh plots. It also illustrates the extreme variability in root concentrations that was occasionally encountered. Each of the smallest dots in the chart represents five fibrous roots, the other dots one root apiece. The soil horizons are as follows: A—dark clay loam, B₁—silt loam with some gravel, B₂—silt loam, gravel and stones, C—coarse sand and gravel, D—coarse sand, E—compact clay, F—coarse sand.

below "significance." It is quite evident from this that within a pH range of 6.0 to 8.0 there was no adverse effect of the higher pH values on root growth. The evidence is not sufficient, however, to state that the lower pH values did show a detrimental effect.

The only elements determined thus far in the soils of the McIntosh plots have been phosphorus and potassium. The major findings in this connection will be reported in subsequent papers. It is pertinent to note at this time, however, that correlations have been made between the concentration of each of these elements in carbonic acid extracts of the soil on the one hand, and the number of fibrous roots on the other hand. With phosphorus, the coefficients of correlation were quite low and non-significant (Table 1). With potassium, the coefficient for the 6- to 24-inch layer was positive and non-significant, but for the whole profile it was positive and highly significant. Since a high correlation (+ 0.878) has been found in these soils between potassium content and moisture holding capacity, it was suspected that the correlations just noted might actually have been due to relationships with soil texture rather than with soil potassium. That this suspicion was correct is suggested by the fact that when the effects of variations in moisture holding capacity were eliminated from the correlation for the profile as a whole, the coefficient was reduced to a negative value (Table 1). As will be noted in a subsequent paper, there has been evidence of actual P and K deficiencies with apple trees in very few of the soils studied, which may explain the lack of correlation between these two elements and the root counts.

Effects of Certain Cultural Treatments

In the spring of 1931, a number of plots were established in the Dominion Experimental Substation orchard at Kelowna, and differential irrigation, fertilizer and other treatments were started in an attempt to control drought spot and corky core of the apple. The effects of these treatments on the growth and yield of the trees have already been reported (20). In other plots, boric acid and borax in varying amounts have been applied annually since 1936 to a number of mature trees. The effects of these treatments on storage quality of the fruit have been reported by Wilcox and Woodbridge (23). Root examinations, as noted under "Procedure," were made in the first series of plots in 1933, 1936, and 1939, and in the boron series in 1939.

In the irrigation series, all plots were irrigated at the same periods, but received varying amounts of water, from one-quarter as much as necessary for satisfactory tree performance up to twice as much as necessary (20). In all cases, drainage was quite satisfactory. When an insufficient amount of water was applied at each irrigation, the lower horizons in the soil dried out and all the roots in these horizons died. After each irrigation, the fibrous roots grew down into the newly-wetted subsoil for a few inches, then died back again, leaving a dense mat of dead or dying rootlets. In the plot receiving twice as much water as necessary, the fibrous roots in the 6- to 18-inch layer were much more numerous than in the plot receiving just sufficient water. In the former of these two plots, the moisture content never fell far below the moisture holding capacity.

In the fertilizer series of plots, sulphate of ammonia was applied at rates of 0, 6 and 15 pounds per tree annually; superphosphate at rates of 0, 4 and 20 pounds per tree annually; and muriate of potash at rates of 0, 2 and 20 pounds per tree annually (20). An examination of the root concentration and distribution failed to reveal any differences that could be attributed to the fertilizer treatments. If there actually were any effects of the fertilizers on the roots, they were effectively masked by other factors.

Two trees were root-pruned in the spring of 1931, by digging trenches down to the gravelly subsoil, in a circle around each tree at 4 feet from the trunk. The same was done with two trees at 7 feet from the trunk, and with two at 10 feet. The rate at which the new roots extended from the cut ends is indicated in Table 2. The distances shown are the greatest recorded at each period. The examination made in 1939 was the most detailed, hence there was more chance of recording the greatest amount of growth. In all cases, the depth at which the most rapid growth occurred was 8 to 14 inches. The 22-foot growth was made largely along a decaying root killed in the root pruning. This indicates how rapidly roots can grow under favourable conditions.

TABLE 2.—RATE OF GROWTH OF NEW ROOTS,
AFTER ROOT PRUNING IN 1931

Radius of root pruning	Distance of new growth		
	1933	1936	1939
feet	feet	feet	feet
4	4	7	22
7	2	4½	11
10	2	3	9

In the boron tests, two trees had received annually 4 pounds of boric acid and 4 pounds of borax, respectively, for four years. In both cases, the foliage had assumed an unhealthy pale appearance, and the fruit was showing breakdown in storage (23). The cover crop was almost all dead from near the trunk out to just beyond the spread of the branches, where the boric acid or borax had been applied. An examination of the apple roots showed that they had all been killed within the area of application down to a depth of about 10 inches with boric acid, and 7 inches with borax. There was also some root killing with the 2-pound applications, but none was observed with applications lighter than this.

Relation to Tree Performance

Correlations were calculated between the number of fibrous roots in each of the 50 McIntosh plots and both terminal length and yield per acre. The results are presented in Table 1 and Figure 7. No relationship was found between the total number of fibrous roots per profile and the terminal length. In view of the high positive correlation between total moisture holding capacity and yield (22), and between total moisture holding capacity and total number of fibrous roots, a high positive correlation might have

been anticipated between the number of fibrous roots and yield. A positive correlation ($+0.127$) was actually obtained, but it was not significant. This lack of significance may have been due to the natural variability in root concentration, as noted above. The best that can be said, however, is that any relationship there may have been between root concentration and yield was largely overshadowed by the effects of other factors.

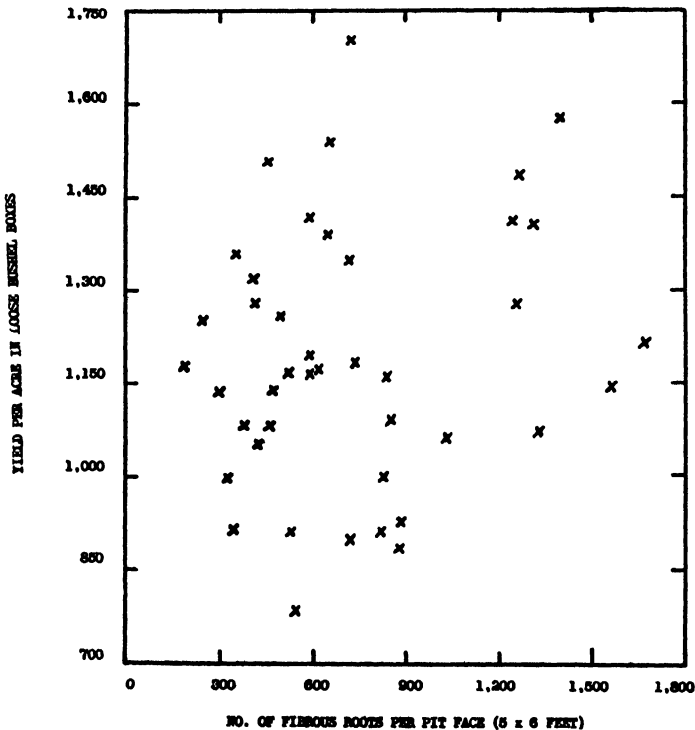


FIGURE 7. Scatter diagram of yield per acre plotted against number of fibrous roots per pit face. Each pit was 5 feet deep. That part of the pit face used consisted of the end nearest the tree (2 feet wide), and a 4-foot length along one side. ($r = +0.127$).

In considering the inter-relationships between yield, moisture holding capacity, and number of fibrous roots, the exceptions to the general trends are of almost as much interest as the trends themselves. In Plot K18 (Table 3), for example, the soil was heavy and deep and the root count was very high, but the yield was low. This appeared to be due primarily to lack of tree vigour, induced by a deficiency of nitrogen. In Plot K25, the soil was heavy and deep, the root count was only medium, but the yield was very high. In Plot B34, the soil was of medium depth, the root count was very high, and the yield was comparatively low. In Plot O19, the soil was light and shallow, the root count was comparatively high, and the yield was low. In Plot K22, the soil was light and shallow and the root count was low, but the yield was comparatively high. In no case, however, were the highest yields associated with very shallow soils or very low root counts. The most important exception to the general trends appears to be the occasional combination of a light, shallow soil with high root concentrations and moderately high yields.

DISCUSSION

In this investigation, only five factors were found to be definitely related to the concentration of fibrous roots in the soil: (1) Depth. The concentration was usually highest between the depths of 6 and 18 inches. (2) Proximity to tree. The closer to the tree (to within at least 5 feet from the trunk), the higher the root concentration. (3) Size of tree. The larger the tree, the greater the root concentration, and the greater the spread and depth of the roots. (4) Soil texture. A moderately heavy loam, containing only sufficient sand or lime to maintain satisfactory permeability, appeared to be the most suitable for the growth of fibrous roots. (5) Soil moisture. A high soil moisture accompanied by good drainage gave the greatest root concentrations in the plots on the Kelowna Substation. Among the factors whose effects were absent, or were too low for measurement with certainty under the variable conditions encountered in the field, were soil pH, phosphorus concentration, potassium concentration, and soil applications of sulphate of ammonia, superphosphate, and muriate of potash.

It is interesting to compare the above findings on the relation of soil texture to apple root concentration with the findings of investigators elsewhere. In deep, well drained profiles in New York, Oskamp and Batjer (9) found higher concentrations of fibrous roots in comparatively heavy soil horizons than in light soil horizons. In shallower profiles subject to excess water, however, better root growth was found in the lighter soil horizons. Sweet (16) in New York obtained similar results to those of Oskamp and Batjer in deep, well drained profiles. Browning and Sudds (1) in West Virginia presented charts showing almost equally good root growth through silty loam and compact clay horizons in the same profiles. Oskamp noted both sandy soil (7) and clay soil (8) horizons too compact for satisfactory root growth. Rogers and Vyvyan (14) in England, Knight (5) in Michigan, and Schuster and Stephenson (15) in Oregon also described heavy clay soils too compact for normal root growth of fruit trees. As already noted, the heavy clay horizons encountered in this investigation were found to prevent root penetration in only two cases. However, penetration has undoubtedly been slower in the heavy soils than in the lighter soils.

It has been assumed in this investigation that in so far as tree performance is concerned, the most important roots are the small fibrous ones; and an attempt has been made to determine the relationships between the relative concentration and total number of fibrous roots on the one hand and tree growth and yield on the other hand. The correlations obtained were all non-significant. This result was somewhat surprising. It was realized (as pointed out by Veatch and Partridge (18) and others) that when there are optimum moisture and nutrient conditions in the soil, a tree can grow and yield satisfactorily with a comparatively small root system. Under optimum conditions in the soil, however, it was anticipated that whether or not the root system was shallow or deep, there would be a very high concentration of fibrous roots in the more favoured horizons (6). This, it was felt, should occur as a result of (1) the direct stimulus of optimum soil conditions on the annual growth and branching of the roots (6, 13, 18), and of (2) the reciprocal effect on the roots of better growth and

health of the top of the tree. Better performance of the top of the tree and greater numbers of fibrous roots should therefore occur together. It is obvious from this investigation that such a relationship does not hold true under all circumstances. For example, in some plots low in nitrogen (K18, O19) the number of fibrous roots was comparatively high but the yield was very low. Although under ordinary circumstances a high concentration of fibrous roots may be considered desirable, it appears that other factors may be of even greater importance in determining tree yields.

It is quite possible that the high concentrations of roots in certain sandy soils and in certain soils low in nitrogen (as noted above), may be attributed in part to the nitrogen relationships. Weaver, Jean and Crist (19) in 1922 reported that applications of nitrogenous fertilizers induced greater branching of roots in the fertilized soil but reduced the extent of root growth. Reid (10) in 1930 found that a somewhat limited supply of nitrogen plus an adequate supply of carbohydrates furnished excellent conditions for root growth. Morris (6) in 1930 reported that apple trees growing in the most fertile soil tested had the shortest roots and the most numerous branches. In this present investigation, it appears that a low supply of nitrogen has in some cases been instrumental in inducing extensive root growth on the one hand but low vigour of the top and low yields on the other hand. This may explain some of the apparent discrepancies already noted (e.g. Plots K18 and O19). In contrast with the findings just quoted, however, it should be noted that some investigators (2, 17) have found an increase in the nitrogen supply to be followed by an increase in both top growth and root growth, the latter increase usually being the lesser of the two.

In the first paper of this series (21), it was reported that the trees occupying less than 900 square feet of ground space bore larger crops of high quality fruit per acre than did those occupying 900 square feet. As already noted in this present paper, the roots gradually fill out the whole volume of soil available, down to depths of at least 8 to 10 feet in a deep soil. This occurs sooner when the trees are planted closer together. The question arises as to whether the crowding of the soil with fibrous roots is automatically followed by a deterioration in tree performance.

Yocum (24) has suggested that in Nebraska, where soil moisture is a limiting factor, the distance apart of planting should be determined in part by the rate of root growth; that is, the more rapid the growth and hence the sooner the soil becomes filled with roots, the further apart the trees should be located. The evidence obtained in this investigation, however, does not point to such a conclusion for irrigated orchards. Some of the highest yielding plots (e.g. K25, K24) consisted of comparatively old trees occupying only 780 square feet of space per tree. In such cases, the continuation of favourable tree performance appears to have been more dependent on continuation of optimum moisture and nutrient conditions than on the presence of a continuous supply of fresh "rootless" soil.

The oldest trees used in this investigation were in Plot K18. It is of interest to note that the whole block of trees in which this plot was located had deteriorated badly by 1937. The trees were low in both vigour and yield, and it looked as if age and crowding had limited their usefulness.

Since then, however, heavy pruning and fertilizing have brought the orchard area in and adjacent to Plot K18 back into excellent growth and production. The change in root concentration since 1939 has not been investigated, but on the basis of records obtained in other orchards the roots should be more crowded now than they were in 1939.

It has been a common practice, in studying the nutrient requirements of an orchard, to take soil samples from the surface foot only. It is true that in most orchards included in this investigation the greatest concentration of fibrous roots is not far from a depth of 1 foot. It is true also that the highest concentrations of organic matter and of certain essential elements (e.g. N, P, K) are usually found in the surface foot of soil⁴. In the deeper profiles, however, the roots may permeate the soil to depths of at least 8 to 10 feet; and it appears logical to assume that they are absorbing nutrients to some extent wherever they go. A complete picture of the nutrient status of the soil does not appear possible as a result of an examination of the surface foot of soil only.

SUMMARY

Trenches were dug near apple trees receiving a number of different cultural treatments. They were made 2 feet wide, at least 5 feet deep, and extended from 3 or 5 feet out to 21 feet from the trunk. The soil horizons and roots along one wall were mapped. In addition, trenches were dug near trees in 50 of the McIntosh plots used for the apple nutrition studies, and the horizons and roots were mapped on a pit face 6 feet long and 5 feet deep. The fibrous roots (less than $\frac{1}{8}$ inch in diameter) were totalled in these 50 trenches, and were correlated with certain soil factors and with tree performance.

The root concentration and distribution were found to be quite variable, even around individual trees. The concentration of fibrous roots tended, however, to be greater (1) with older trees, (2) closer to the trunk, and (3) between the depths of 6 and 24 inches. A grass sod lessened the number of apple roots in the surface 6 inches. In deep soils, the roots of older trees filled the soil to a depth of at least 8 feet. In shallow soils, underlain by clear sand and gravel, the roots seldom grew down more than a foot into the sandy subsoil, except right under the trees.

In deep, heavy soils, the roots tended to be less concentrated in sandy layers and in heavy, laminated clay layers. In sandy or light loam soils, they tended to be more concentrated in the heavier layers. In the 50 McIntosh plots the total number of fibrous roots per profile was correlated positively with the total moisture holding capacity per profile. No adverse effect of carbonates was noted. Within a pH range of 6.0 to 8.0, the higher pH values were associated with the greater number of roots. The concentrations of available phosphorus and potassium in the soil showed no significant correlation with the numbers of fibrous roots.

Among the treatments studied, heavy watering accompanied by good drainage favoured the growth of fibrous roots. There were no observable effects of applications of sulphate of ammonia, superphosphate, or muriate of potash; but heavy applications of borax and boric acid killed the fibrous roots in the surface soil.

⁴ Further data on this will be published in subsequent papers.

No relationship was found between the number of fibrous roots and tree vigour. A positive but non-significant correlation was obtained between the number of fibrous roots and yield. It is concluded that factors other than number of roots were more important in determining tree performance.

ACKNOWLEDGMENT

The authors wish to acknowledge the assistance of Mr. H. E. Trimble and Mr. S. D. Dyson in conducting the field work reported herein. They also wish to express their appreciation for editorial comments made by Mr. R. C. Palmer and Mr. A. J. Mann of the Dominion Experimental Station at Summerland.

REFERENCES

1. BROWNING, G. M. and R. H. SUDDS. Some physical and chemical properties of the principal orchard soils in the Eastern Panhandle of West Virginia. *West Virginia Agr. Exp. Sta. Bull.* 303. 1942.
2. CHANDLER, W. H. Some results as to the response of fruit trees to pruning. *Proc. Amer. Soc. Hort. Sci.* 16 : 88-101. 1919.
3. GARDNER, V. R., F. C. BRADFORD and H. D. HOOKER. The fundamentals of fruit production. McGraw-Hill Book Co., New York. 1939.
4. KELLEY, C. C., R. H. SPILSBURY and L. FARSTAD. Soil survey of the Okanagan and Similkameen Valleys. (Unpublished).
5. KNIGHT, A. T. The influence of porosity of some orchard soils upon root behavior. *Proc. Amer. Soc. Hort. Sci.* 40 : 23-26. 1942.
6. MORRIS, O. M. Apple tree roots. *Proc. Washington State Hort. Ass.* 26: 95-97. 1930.
7. OSKAMP, J. Soils in relation to fruit growing in New York. VI. Tree behavior on important soil profiles in the Williamson-Marion area, Wayne County. *New York (Cornell) Agr. Exp. Sta. Bull.* 626. 1935.
8. OSKAMP, J. Soils in relation to fruit growing in New York. IX. Tree behavior on important soil profiles in the Newfane-Olcott area, Niagara County. *New York (Cornell) Agr. Exp. Sta. Bull.* 653. 1936.
9. OSKAMP, J. and L. P. BATJER. Soils in relation to fruit growing in New York. II. Size, production, and rooting habit of apple trees on different soil types in the Hilton and Morton areas, Monroe County. *New York (Cornell) Agr. Exp. Sta. Bull.* 550. 1932.
10. REID, MARY E. Growth of tomato cuttings in relation to stored carbohydrate and nitrogenous compounds. *Amer. Jour. Bot.* 13 : 548-575. 1926.
11. RICE, T. D. and L. T. ALEXANDER. The physical nature of soil. U.S. Dept. of Agr. Yearbook for 1938, 887-896.
12. ROGERS, W. S. Root studies. VII. A survey of the literature on root growth; with special reference to hardy fruit plants. *Jour. Pom. Hort. Sci.* 17 : 67-84. 1939.
13. ROGERS, W. S. Root studies. VIII. Apple root growth in relation to rootstock, soil, seasonal and climatic factors. *Jour. Pom. Hort. Sci.* 17 : 99-130. 1939.
14. ROGERS, W. S. and M. C. VYVYAN. Root studies. V. Rootstock and soil effect on apple root systems. *Jour. Pom. Hort. Sci.* 12 : 110-150. 1934.
15. SCHUSTER, C. E. and R. E. STEPHENSON. Soil moisture, root distribution and aeration as factors in nut production in Western Oregon. *Oregon Agr. Exp. Sta. Bull.* 372. 1940.
16. SWEET, A. T. Soil profile and root penetration as indicators of apple production in the Lake Shore district of western New York. U.S. Dept. Agr. Circ. 303. 1933.
17. TURNER, T. W. Studies of the mechanism of the physiological effects of certain mineral salts in altering the ratio of top growth to seed growth in seed plants. *Amer. Jour. Bot.* 9 : 415-446. 1922.
18. VEATCH, J. O. and N. L. PARTRIDGE. Response of fruit tree growth to the soil complex reached by roots. *Proc. Amer. Soc. Hort. Sci.* 29 : 208-212. 1932.
19. WEAVER, J. E., F. C. JEAN and J. W. CRIST. Development and activities of roots of crop plants. *Carnegie Inst. Wash. Pub.* 316. 1922.
20. WILCOX, J. C. Effects of some field plot treatments on drought spot and corky core of the apple. *Sci. Agr.* 18 : 300-314. 1938.
21. WILCOX, J. C. Some factors affecting apple yields in the Okanagan Valley. I. Tree size, tree vigour, biennial bearing, and distance of planting. *Sci. Agr.* 25 : 189-213. 1944.
22. WILCOX, J. C. Some factors affecting apple yields in the Okanagan Valley. II. Soil depth, moisture holding capacity, pH, and organic matter content. *Sci. Agr.* 25 : 739-759. 1945.
23. WILCOX, J. C. and C. G. WOODBRIDGE. Some effects of excess boron on the storage quality of apples. *Sci. Agr.* 23 : 332-341. 1943.
24. YOKUM, W. W. Root development of young Delicious apple trees as affected by soils and by cultural treatments. *Nebraska Agr. Exp. Sta. Res. Bull.* 95. 1937.

APPENDIX

TABLE 3.—NUMBERS OF FIBROUS ROOTS COUNTED ON WALLS OF TRENCHES IN MCINTOSH PLOTS*

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Plot No.	Ave. depth of roots inches	By depth, in feet†						By distance from tree, in feet‡					Total
		0-½	½-1	1-2	2-3	3-4	4-5	5	5-6	6-7	7-8	8-9	
K1	14	62	92	27				33	27	24	34	30	181
K2	19	87	183	76				79	50	61	40	37	346
K6	16	20	169	145				62	108	65	24	13	334
K7	40	14	117	147	104	43		75	74	83	74	43	425
K8	55	7	148	258	171	91	48	134	111	132	107	103	722
K9	28	151	168	175	40			93	104	75	91	78	534
K10	24	117	320	144				133	125	66	76	47	581
K11	14	36	184	17				43	46	29	40	35	237
K14	22	12	252	146				73	86	74	59	45	410
K15	17	41	231	66				55	60	54	59	55	338
K16	48	151	120	112	119	105		102	104	105	96	98	607
K17	34	36	217	276	79			120	93	104	97	73	608
K18	60+	129	229	338	194	117	149	188	196	206	225	153	1156
K21	20	21	166	112				46	37	48	52	69	299
K22	17	182	170	45				56	69	73	75	67	397
K24	60+	71	143	119	24	23	69	97	83	45	55	71	449
K25	51	49	136	208	158	71	29	95	91	113	122	135	651
K27	40	90	215	132	36	72		110	86	87	68	83	545
K39	26	95	84	131	14			63	75	48	42	33	324
K44	17	257	195	72				102	113	82	59	65	524
K46	17	196	243	33				119	74	43	59	58	472
K48	60+	40	228	545	342	109	46	222	227	214	184	241	1310
K49	51	49	167	174	206	80	39	148	152	125	81	60	715
K51	17	62	206	106				65	66	66	55	60	374
K53	22	164	167	72				88	60	54	59	54	403
K54	18	202	326	67				160	102	36	71	65	595
B1	60+	71	204	261	139	95	87	137	153	143	139	147	857
B29	28	42	146	217	55			87	60	70	74	81	460
B30	34	42	159	194	125			99	87	83	84	67	520
B31	27	30	173	327	55			83	127	126	99	68	585
B33	51	31	267	436	274	171	70	237	229	209	201	136	1249
B34	34	92	349	661	225			238	198	194	222	236	1327
B36	27	122	305	379	79			153	163	175	120	121	885
B37	26	44	316	331	28			103	123	156	124	109	719
B38	28	92	398	311	43			160	201	114	96	112	844
G19	60+	215	380	303	176	223	261	299	266	204	251	238	1558
G20	56	202	467	517	343	96	43	268	330	276	270	256	1668
W2	60+	218	220	255	194	79	65	210	165	145	127	173	1031
W4	26	69	122	178	11			58	24	54	121	65	380
W5	36	63	112	217	86	13		108	129	88	36	22	491
W6	30	146	237	366	73			104	142	195	162	114	822
W7	25	90	130	105	4			44	45	39	78	78	329
W8	42	243	456	278	218	67		294	192	158	184	139	1262
W9	60+	64	338	494	209	158	125	293	277	198	152	175	1388
W10	60+	71	205	181	88	41	47	99	129	96	83	126	633
O14	60+	78	378	343	158	179	119	209	197	226	235	178	1255
O15	27	1	141	539	55			198	135	107	60	37	736
O17	49	110	223	234	210	47	7	139	136	133	163	121	831
O18	28	357	625	486	47			259	237	335	239	187	1517
O19	29	176	285	253	67			142	159	187	134	116	881

* By "fibrous" roots is meant those roots less than ½ inch in diameter.

† Each figure represents the number of fibrous roots in 6 feet length of pit face, at the depth noted. The "totals" are obtained by adding these figures.

‡ Each figure represents the number of fibrous roots from 0 to 5 feet in depth, at the distance from the tree noted. The figures for the 5-foot distance are obtained by averaging the 2 feet of pit face nearest the tree.

"LAMBERT MOTTLE", A TRANSMISSIBLE DISEASE OF SWEET CHERRY¹

T. B. LOTT²

Dominion Laboratory of Plant Pathology, Summerland, B.C.

[Received for publication July 20, 1945]

In 1939, previously unobserved symptoms appeared in four experimental Lambert trees in the laboratory grounds. These symptoms were at first thought to be those of mottle leaf on the Lambert variety. They were later shown to be due to a separate and distinct transmissible disease. The name "Lambert mottle" is suggested because Lambert is the only variety known to show symptoms.

OCCURRENCE

The four experimental Lambert trees in which "Lambert mottle" was first observed had all been used in attempts to transmit mottle leaf to the Lambert variety. This mottle leaf had been originally obtained from a Napoleon (Royal Anne) tree in Nelson City in the Kootenay District. Examination of most of the cherry trees in that city showed considerable mottle leaf in the Bing, Napoleon, and Republican varieties but no "Lambert mottle" in the Lambert variety. Surveys made in the Okanagan Valley between 1938 and 1941 covered over 9,000 cherry trees, nearly all of which were of the sweet varieties, but revealed only 9 trees naturally infected with "Lambert mottle."

SYMPTOMS

Only the Lambert variety is known to show symptoms (Figure 1). The terminal shoots of trees in which the disease is well established appear normal in the early spring, but, as the season advances, all the upper buds on many of them either fail to move, or swell a little and then die. The development of the other leaf buds and of the flower buds is both late and irregular. In the early summer, the foliage appears slightly thin, but individual leaves are normal in appearance and most of them are full size. In early June a slight yellow interveinal mottle begins to appear on the older leaves, and is soon followed by numerous small spots of a purplish or chocolate colour which later becomes more brown. These spots form lines close beside the veins, and also irregular lines and rings or partial rings without relation to the veins. The lines of minute purplish spots are usually surrounded by a poorly defined area of a greenish yellow. In some leaves a similar greenish yellow pattern occurs without any purple spots. In addition to these symptoms, and occurring without apparent relation to them, there are areas of the leaf up to 3 cm. in length which become brown and ~~dark~~ but do not usually separate clearly at the margin. Typically the margins of these areas are irregularly curved but sometimes a sharp point extends along a small vein. The brown areas occur on any part of the leaf blade except the mid-rib. In midsummer the basic normal green of the oldest leaves changes to yellow while the greenish yellow

¹ Contribution No. 824 from the Division of Botany and Plant Pathology, Science Service, Department of Agriculture, Ottawa, Canada.

² Agricultural Assistant.

pattern becomes slightly more green. Defoliation varies from year to year. It may commence with the oldest leaves in early July and half of the leaves may fall prematurely. The one symptom which can be observed at all times is the form of branching that results from the production of new shoots from part way down the previous season's growth. Diseased trees set only a light crop and sometimes many of the fruits do not reach maturity. In some cases fruits of normal size and colour have abnormally short and curved pedicels. In some trees nearly all of the fruits arise from fruit buds carried either singly on the lower part of the 1-year-old wood or on a few spurs on the upper or outer part of the 2-year-old wood. The small number of growing fruit spurs may be very pronounced. The disease becomes progressively more serious for several years and the death of twigs and larger branches occurs. The death of whole trees has not been observed but there are some indications that young trees may be killed in course of time. In older trees the disease appears to become stabilized.

EXPERIMENTAL WORK

Unless otherwise stated, all experimental trees were young trees growing out-of-doors, and all attempted transmissions were made by grafting tissue from diseased trees onto healthy ones either by shield budding in the summer or by grafting dormant scions in the spring.

"Lambert mottle" has been transmitted to 17 Lambert trees and every attempted transmission has given positive results. The disease has been transmitted to Lambert six times from Bing tissue and eleven times from Lambert tissue. It has been transmitted to Lambert from four sources: a Napoleon source in Nelson containing mottle leaf also, and three Lambert sources in the Okanagan Valley containing "Lambert mottle" only. Attempts to transmit "Lambert mottle" to Bing and Napoleon trees from these four sources and from one other Lambert source in the Okanagan Valley produced no visible effect of "Lambert mottle" in 27 Bing trees and 14 Napoleon trees. Diseased Lambert branches grew in some of these trees for years with no visible effect on the rest of the tree. No attempts have yet been made to demonstrate the presence of the virus in these Bing and Napoleon trees. Normal Bing buds set on a diseased Lambert tree produced branches which grew normally till the Lambert tree was nearly dead. Some of the Bing leaves then showed a few rather bright yellow ring spots. "Lambert mottle" was transmitted to two Lambert trees from buds taken from these Bing branches.

Attempts to transmit mottle leaf, originally obtained from the above-mentioned Napoleon source in Nelson, to two pairs of Lambert trees produced "Lambert mottle" in all of the trees. The first pair of Lambert trees had been started in pots in the greenhouse and had received single- or multiple-bud dormant scions from a Bing tree infected directly from the Napoleon source in Nelson. No symptoms appeared in the greenhouse and the trees were soon planted out-of-doors where symptoms of "Lambert mottle" appeared later. From each of this pair of Lambert trees "Lambert mottle" was transmitted to 2 Lambert trees and mottle leaf was transmitted to 4 Bing trees and 2 Napoleon trees, showing that the two viruses were both present in this pair of Lambert trees which showed symptoms of

"Lambert mottle" only. The second pair of Lambert trees had been treated with material from a Bing tree infected with mottle leaf as a result of being splice-grafted to the Bing tree infected directly from the Napoleon source in Nelson. Dr. H. R. McLarty had taken scrapings of the cambium from the diseased tree and inserted these cambium scrapings under the bark of the healthy trees. From this pair of Lambert trees "Lambert mottle" was transmitted to 3 Lambert trees, transmission being obtained



FIGURE 1. Symptoms of "Lambert mottle."

- A. Left, diseased shoots showing late and irregular development and death of terminal buds. Right, normal.
- B. Pattern on a green leaf.
- C. Pattern and brown torn areas on a yellow leaf.
- D. A young diseased Lambert tree, September, 1939.
- E. The same tree, October, 1944.

from each tree of the pair. No mottle leaf, however, was transmitted to any of the 9 Bing trees and 6 Napoleon trees that received scions or buds from this pair of Lambert trees, showing that this pair of Lambert trees contained the "Lambert mottle" virus but did not contain the mottle leaf virus. Thus in this experiment "Lambert mottle" and mottle leaf were both transmitted by budding and grafting, but only "Lambert mottle" was transmitted by cambium scrapings inserted under the bark, although in a different experiment mottle leaf had been transmitted by cambium scrapings. Mottle leaf produces pronounced symptoms on Bing and Napoleon trees but has little or no effect on Lambert trees. "Lambert mottle" produces marked symptoms on Lambert trees but no definite symptoms have so far been observed on Bing or Napoleon trees. In Bing trees, from which "Lambert mottle" was transmitted to Lambert trees, the symptoms were indistinguishable from those of mottle leaf alone. Lambert trees, carrying both diseases, showed only "Lambert mottle" and the presence of the other disease had no visible effect.

Leaf symptoms of "Lambert mottle" appeared in the first year after budding. Symptoms on the twigs began to appear in some trees in the second year. Later the disease became progressively more serious in some trees while in others it appeared to become stabilised.

SUMMARY

1. A new transmissible disease of sweet cherry is described.
2. The disease is only known to produce symptoms on the Lambert variety.
3. It has occurred naturally, both alone and together with mottle leaf, but it is rare.
4. Transmission to Lambert trees has been obtained without fail.
5. Pronounced symptoms are produced by "Lambert mottle" on Lambert trees and by mottle leaf on Bing and Napoleon trees, but there is little or no visible effect of "Lambert mottle" on Bing or Napoleon trees, or of mottle leaf on Lambert trees. When both diseases are present in a tree the symptoms depend on the variety of the tree and only one disease is visible, the other having no apparent effect.

SOLONETZ SOILS IN ALBERTA

WM ODYNSKY¹

University of Alberta, Edmonton, Alberta

[Received for publication July 6, 1945]

Solonetz is a term first used in the Russian literature for a soil that is believed to have developed from a structureless, often salt encrusted, saline soil. Under favourable conditions this development has resulted in a soil that has a very tight subsoil with a distinct and characteristic structure. While the mechanism of, and the conditions necessary for this development is not as yet clearly understood, the resultant structure is strikingly different from that of other soils. Soils having this unfavourable structure are known to occur in scattered patches and occasionally as large unbroken areas throughout the more arid sections of the world. They are of fairly common occurrence in the Great Plains area of the United States, and in Western Canada. Large areas have been outlined in Alberta (see map, Figure 1) and further soil surveys will no doubt extend the present reported acreage considerably.

Prior to the use of the term solonetz, such soils were called by a variety of local names the most common of which were "blow-out," "burn-out," "buffalo-wallow," "slick-spot" or "gumbo-spot" soils. Areas of such soils are frequently characterized by a patchy, pitted surface (Figure 2) which has given rise to the variety of local terms in common use. Such soils are droughty, difficult to break up, difficult to handle and generally inferior agricultural soils. This inferiority seems to be due largely to the unfavourable characteristics of the subsoil and is most marked when this subsoil is encountered within plow depth.

Typical solonetz profiles in Alberta have the following characteristics:

Horizon A

A rather porous soil that is often slightly granular. It can readily be broken up into small irregular lumps or clods that have considerable fine powdery material. The colour of this horizon may vary from a brown to a black depending on the soil zone. Frequently it is somewhat grayer than the A horizon of typical zonal soils. It varies in thickness from 2 inches to 24 inches, although most frequently it is from 4 inches to 10 inches thick. It tends to be shallower in the brown and dark brown soil zones than in the black and gray. While its texture is most frequently a loam or a silty loam, it does vary from a loamy sand to a clay. Frequently the lower part of this horizon is characterized by a gray, finely laminated or foliated structure. This platy A₂ subhorizon may vary from merely a thin layer to a thickness of a few inches.

Horizon B

The characteristics of this horizon form the principal and most distinctive feature of the solonetz. Usually three subhorizons can be distinguished as follows:

Sub-Horizon B₁. A very compact horizon that becomes sticky and water tight when wet and very hard when dry. On drying it breaks into

¹ Soils Specialist, Dominion Experimental Farms Service.

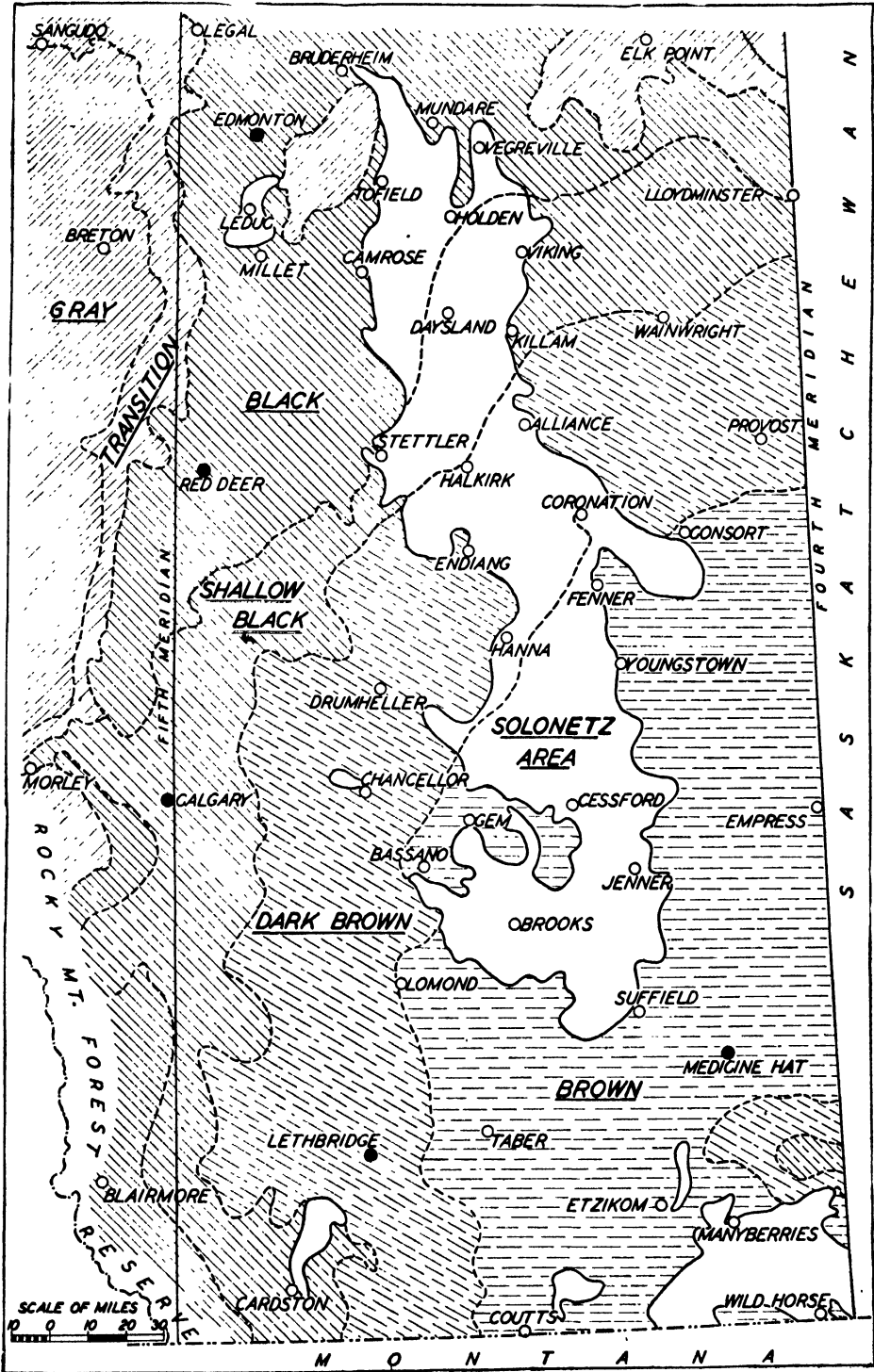


FIGURE 1. Map of a Portion of Alberta Showing Soil Zones and Solonetz Areas.

coarse angular columns often characterized by a well rounded cauliflower-like top (Figure 8). For a depth of about $\frac{1}{8}$ inch these columns are often capped with a grayish, very hard, dense layer. The columns are usually about 1 to 2 inches wide and rarely more than 8 inches long. They are made up of very hard small angular clods which are often coated with a dark shiny film that gives them a somewhat waxy or glazed appearance.

Sub-Horizon B₂. Here the vertical cracks that separate the columns become more irregular and break the soil mass into rough irregular cubes. The glazed appearance of the small clods is less marked and is frequently absent in the lower part of this sub-horizon. The material is not as compact or as impermeable as that in the B₁.

Sub-Horizon B₃. This has usually much the same structure as the B₂ but contains lime and very frequently considerable quantities of gypsum within a short distance below the top of the lime layer. It is usually lighter in colour, often mottled, and is much more permeable than the B₂ sub-horizon.

The depth to and thickness of these sub-horizons vary with the location, the soil zone, and with the nature of the underlying parent material. The B₁ varies from 3 to 8 inches in depth, the B₂ from 6 to 24 inches and the B₃ is encountered at depths varying from 12 to 36 inches below the surface.

The B₁ is the darkest coloured of these and it may be a greasy black, dark brown, drab gray or olive gray. Below the B₁ the colour gets lighter and grades without any sharp changes into that of the parent material. In the brown and dark brown soil zones the colour of the B₁ is frequently darker than that of any other horizon in the profile.

The contact between the A and B horizons is characteristically very abrupt and clear-cut, totally unlike that of other soils. In the latter there is a very irregular and often indistinct break between these horizons.

Usually the texture of the B horizon is a clay or clay loam. The B₁ sub-horizon is the heaviest and frequently has an accumulation of the very fine clay particles.

Horizon C

This horizon varies in different regions as regards its depth and texture, and its characteristics depend on the derivation of the parent material. In some cases it may be found within 18 inches of the surface but more frequently it is found at depths greater than 24 inches below the surface. It may consist of water or wind laid deposits, glacial till, or in many cases of the somewhat mixed or sorted products of the underlying bedrock. In the latter case its depth is usually quite shallow and the bedrock is relatively close to the bottom of the B₃ horizon.

In the samples studied to date the pH of the A horizon varies from mildly alkaline in the brown soil zone to mildly acid in the black soil zone. Alkalinity increases with depth; the B₁ horizons average about pH 7.6, the B₂ about pH 8, and the B₃ and C about pH 8.2. Comparable non-solonetz soils have about the same or slightly less acid A horizons, generally somewhat less alkaline B₁ horizons and about the same alkalinity in their remaining horizons.

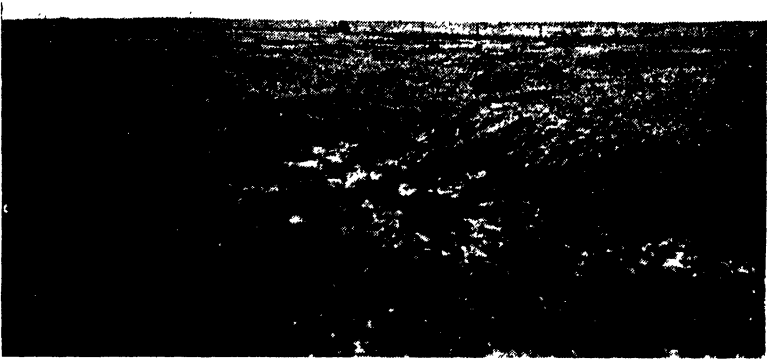


FIGURE 2. Typical Solonetz topography in the brown and dark brown soil zones. Note the pitted nature and in the foreground the depth of A horizon overlying the frequently exposed B horizon.



FIGURE 3. Eroded cut showing very close proximity of underlying bedrock. This is typical of much of the flat solonetz area in the neighbourhood of Cessford, Coronation, Halkirk and Holden.



FIGURE 4. Solonetz topography in the Black and Shallow Black Soil Zones. Flooded patches such as shown are typical during and sometimes after rainy spells. Such soils absorb water very slowly.

The horizons described are, in most cases, true genetic horizons, and as such one might expect them to reflect a definite chemistry of soil formation. However, there is as yet considerable difference of opinion regarding this point.

Kellog (3) in discussing these soils says in effect: "The solonetz represents one stage in a cycle of one group of saline soils. The group required is the alkaline group or that in which sodium salts predominate. If the group had a predominance of calcium salts rather than sodium no solonetz would be formed." The solonetz soils studied to date in Alberta, and reported by MacGregor and Wyatt (4), have had calcium predominant in the base exchange. As these authors point out, similar studies elsewhere on this continent have shown that with but one exception, calcium and magnesium are predominant rather than sodium. As a result, some pedologists have been hesitant to use the name solonetz. However, considering the widely divergent views, it seems obvious that until such time as more convincing proof is available these soils cannot be strictly defined in chemical terms, especially in regard to the nature of their base exchange complex. They can easily be recognized by their structure and it is mainly this structure that sets them apart from other soils. Furthermore it is doubtful if solonetz soils always represent but one stage in a cycle of one group of saline soils. Our observations lead us to agree with Nikiforoff's (6) suggestion that very often the solonetz and the other saline members "may be genetically independent soil formations whose development and distribution is controlled by different factors."

Although considerable of Alberta's solonetz soils occur as occasional patches of varying size intermixed and forming complexes with other soils, their most striking occurrence is in the belt (see map, Figure 1) that extends from Bruderheim to near Suffield, a distance of about 250 miles. This belt averages about 35 miles in width and attains its maximum width of approximately 60 miles in the vicinities of Brooks and Coronation. Patches of solonetz of varying size and not as yet outlined occur north of this belt and a fairly large area occurs south of this belt lying between Manyberries and Wild Horse in the south east part of the province. This latter area has much the same characteristics as the southern portion of the main belt and it may have been, at one time, a part of that belt. However, it is separated now by an area in which the prevailing conditions seem to be generally unfavourable to the development of solonetz. Outside of these, many small areas have been mapped and the largest, occurring near Etzikom, Coutts, Cardston, Chancellor and Leduc, have been outlined on the accompanying map. Solonetz areas are also known to occur in the neighbourhood of Breton, Legal, and between Red Deer and Millet, but their boundaries have not yet been determined. Similarly in the area north of that shown on the map solonetz patches of undetermined size are known to occur at or near Gibbons, Busby, Clyde, Grande Prairie, Fairview and Grimshaw.

As indicated on the map the solonetz area extends through the brown, dark brown, shallow black and black soil zones of the province. Solonetz soils are also known to occur in the transition and gray soil zones. In addition they are found under a wide range of soil textures. However,

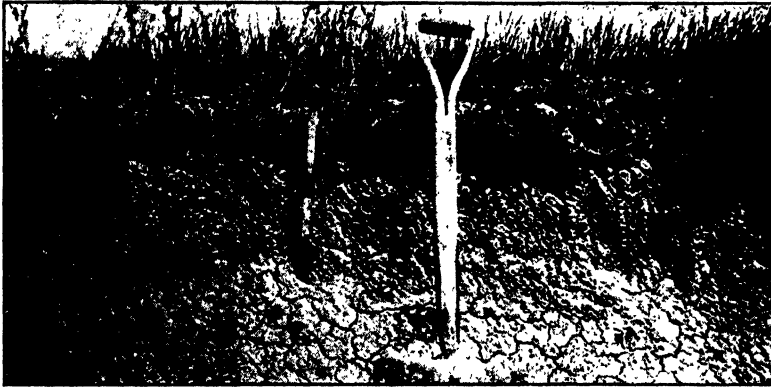


FIGURE 5. Solonetz profile typical of much of the flat solonetz area in the black and shallow black zone. In old road cuts, such as this, the columnar structure of the upper part of the B horizon is obscured due to the effects of weather.



FIGURE 6. A deeper phase fine sandy loam solonetz profile. In the brown and dark brown soil zones the occurrence of this tight horizon at depths of about 24 inches often improves the agricultural value of such light sandy areas.

while they seem to occur over a wide range of parent materials their best development has been found in areas closely underlain by brackish marine shales and sandstones.

The main belt of solonetz soils is found in a trough that lies between the Viking and Buffalo Lake moraines (8). The area within this trough is level to undulating and is covered over, for the most part, by a shallow mantle of glacial till. This shallow mantle lies either directly on the bedrock (Figure 3), or is sometimes separated from it by other unconsolidated deposits that are chiefly alluvial. The bedrock in this area consists of the Bearpaw formation, the lower members of the Edmonton formation and the upper members of the Belly River formation as outlined and described by Allan (1). These formations are bentonitic and contain varying amounts of soluble salts. The salty impermeable nature of these beds and the relatively thin covering of glacial till may have furnished conditions favourable to the development of this large solonetz belt.

The areas as outlined on the map represent approximately 7 million acres or 20% of the area lying south and east of Edmonton and east of the fifth meridian. In these areas solonetz soils are either continuous or form not less than 20% of a mixture, and those in which the B horizon occurs at depths less than 12 inches below the surface. Outside of the solonetz areas shown on the map there are in addition at least 3 million acres of soils in which the B horizon occurs at depths greater than 12 inches below the surface. In light, sandy soils the presence of the tight horizon at depths greater than 12 inches (Figures 6 and 7) seems to improve their value as arable soils because of its water retention.

The large amount of abandonment that has occurred in the outlined areas is evidence of the fact that these soils are inferior agricultural soils. Their inferiority becomes more pronounced in dry years or prolonged periods of drought. Regardless of the conditions that may have been necessary for their formation, they are not now alkaline soils. Neither are they any more deficient in total plant food than other neighboring soils. Their inferiority seems to be due to the unfavourable physical condition of the B horizon—particularly the B₁ sub-horizon—which tends to restrict the feeding range of plants. In this connection Hide (2), studying the causes of certain unproductive spots in the black soils of the Red River Valley, concluded that these spots will not appear when the subsoil has been well supplied with moisture by means of a preceding season of clean fallow, by exceptionally favourable rains or by irrigation.

While it is desirable that there should be an adequate supply of moisture it is at least equally desirable that this supply be available to the plant roots. In his review of the literature regarding the "Plant Growth Relations on Saline and Alkali Soils" Magistad (5) points out that in such soils there is a decrease in available water due to the high osmotic pressure of the soil solution. Direct measurements have shown that water absorption by plants is reduced as the osmotic pressure of the subsoil is increased. He adds that some of these soils take on unfavourable physical properties in that they become dispersed, do not drain well, and will not readily "take" water with the result that plants grown on them may suffer from an actual lack of water, a lack of oxygen in the soil air, a lack of



FIGURE 7. A sandy loam solonetz profile in the dark brown soil zone. Note the variable depth of the A horizon. In heavier textured solonetz soils the surface is usually much shallower.



FIGURE 8. A portion of the B horizon of a typical solonetz profile. Note the cauliflower like appearance of the top of the B₁ sub-horizon and the columnar structure of the upper 4 inches. These "round tops" are capped by a very hard, dense layer. The portion on the left side nearest the rule is a side view, while that on the right is a top view.

available nutrients and many other nutritional disorders. It would seem very desirable therefore to adopt some means of culture that would lead towards breaking and loosening up this horizon and then keeping it loose to promote an adequate movement of both air and water and enable plant roots to more easily penetrate this horizon. Experimental work (7) conducted on solonetz soils in the dark brown zone of Saskatchewan has shown that some improvement in tilth can be obtained by raising sweet clover, applying farm manure, occasional deep plowing, frequent summerfallowing, and a thorough preparation of the seedbed.

In the brown soil zone of Alberta past experience indicates that it is very difficult to adopt a satisfactory economical means of opening up this compact subsoil typical of solonetz. The low average annual precipitation of 12 inches makes the growing of such deep rooted soil improving crops as alfalfa and sweet clover very uncertain. Crested wheat grass while not as desirable a soil improving crop, is better adapted to this zone and if seeded down and left for several years it might improve the tilth of these areas. At any rate it would improve the pasture in areas where the present stand in many places is quite poor. At the present time much of the non-irrigated solonetz area in this zone is poor arable land and where once farmed is now mostly abandoned. The problem is a serious one since solonetz soils occupy about one-third of the area of the brown soil zone.

In the dark brown, shallow black, black, transition and gray soil zones these areas although difficult to work and uncertain of success might be improved with less difficulty. The average annual precipitation of from 15 to 20 inches is much more favourable and in seasons of good moisture many of the solonetz areas in these zones have produced good crops. With deep plowing and the establishment of alfalfa in the moister sections, and sweet clover in the drier sections, some hope of permanent improvement might be expected. However, it must be borne in mind that this process of improvement is a continuous one and the growing of soil improving crops and occasional deep plowing must be recognized as permanent features of the crop rotation. In these areas of more favourable moisture the solonetz are not so badly pitted and the depth to the B horizon is somewhat greater than is the case in the brown soil zone. Nevertheless solonetz soils must still be considered as definitely inferior soils. Successful reclamation seems to depend largely on the depth to the B₁ horizon, and on the depth to and the nature of the underlying parent material. In these zones abandonment has largely occurred in those solonetz areas in which bedrock occurs within a few feet of the surface (Figures 3, 4, and 5).

Much of the southern part of Alberta is receiving favourable consideration for future irrigation schemes. In some cases portions of the areas under consideration consist of solonetz soils. Under irrigation, there is no doubt that some of these soils will prove very satisfactory. The outstanding example of the successful reclamation of solonetz soils through irrigation is to be found in the vicinity of Brooks. With the judicious use of water, accompanied by the raising of deep rooted soil-improving crops, the compact layer of the solonetz has been broken up sufficiently to permit of good growth (Figure 9). However, in this area the underlying C horizon

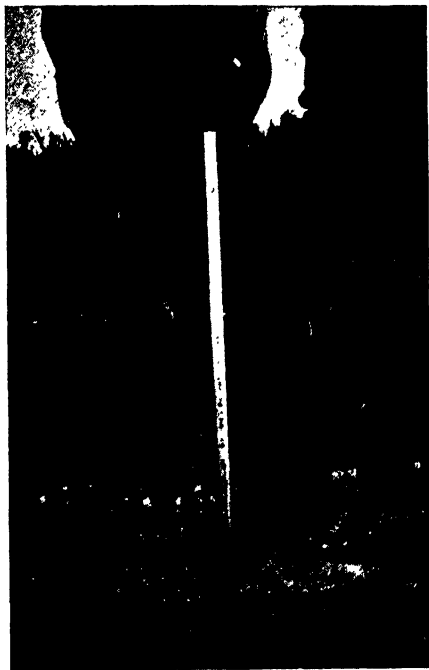


FIGURE 9. A profile typical of the medium textured irrigated soils of the Brooks area. The area has been levelled over, and while there is still a distinct and sharp break between the A and B horizons, the latter has lost much of its compact characteristics through irrigation and the growing of deep rooted crops.

consists of stratified sedimentary deposits of considerable depth that are quite permeable and permit ready percolation, once the heavy compact layer has been penetrated. It is unwise to assume on the basis of the success in the Brooks area, that all solonetz soils are amenable to irrigation. Those that do not have such a favourable subsoil or a desirable slope may on irrigation become waterlogged and saline.

SUMMARY

Solonetz soils have a very tight subsoil with a distinct and characteristic structure. Such soil areas are characterized by a patchy pitted surface that has given rise to the variety of local names used for them. They are of frequent occurrence in Alberta, and only the shallower of the continuous variety or of the mixed type in which solonetz soil represents not less than 20% of the mixture have been outlined in the solonetz areas. These areas represent a total of about 7 million acres in that part of Alberta lying south and east of Edmonton, and east of the fifth meridian. Their most extensive development has been found in areas closely underlain by brackish marine shales and sandstones, and their most striking occurrence is in the trough lying between the Viking and Buffalo Lake moraines.

Solonetz soils are inferior agricultural soils, and their inferiority seems to be due to the unfavourable condition of the B horizon. Improvement in tilth can be expected only if some means of culture is adopted that will

lead towards breaking and loosening up this horizon and then keeping it loose. In the brown soil zone of Alberta past experience has shown that it is very difficult to adopt an economical practice that will improve the soil. In the other zones, where moisture is not such a limiting factor, the growing of such deep rooted soil-improving crops as alfalfa and sweet clover may bring lasting improvement if such crops are included as permanent features of the crop rotation. The success of irrigation on solonetz soils seems to depend largely on the nature and depth of the material underlying the B horizon.

ACKNOWLEDGEMENT

The help of members of the Alberta Soil Survey in outlining the solonetz areas, collecting samples and making analyses, and of Dr. F. A. Wyatt's advice and suggestions, is gratefully acknowledged.

REFERENCES

1. ALLAN, J. A. Research Council of Alberta Report No. 34, 1943.
2. HIDE, J. C. The causes of certain unproductive spots in the Red River Valley. University of Minnesota, Ph.D. Thesis. 1935.
3. KELLOG, C. E. The Soils That Support Us, Macmillan Co., N.Y., pp. 123-129. 1941.
4. MACGREGOR, J. A. and F. A. WYATT. Studies on Solonetz Soils of Alberta. Soil Sci. In press.
5. MAGISTAD, O. C. Plant growth relations on saline and alkali soils. Bot. Rev. 11 : 181-230. 1945.
6. NIKIFOROFF, C. C. The Solonetz-like soils in southern California, Jour. Am. Soc. Agron. 29 : 781-796. 1937.
7. SACKVILLE, E. C. The improvement of burn-out lands in southern Saskatchewan. Pub. 600, Dom. Dept. of Agric. 1938.
8. WARREN, P. W. The significance of the Viking moraine. Trans. Roy. Can. Inst. 21 : 301-305. 1937.

DÉTERMINATION DU MAGNÉSIUM ÉCHANGEABLE DANS LES SOLS PAR LA 8-HYDROXYQUINOLÉINE¹

MICHEL A. PINEAU² ET LUCIEN CHOINIERE³

[Reçu pour publication janvier 29, 1945]

D'après plusieurs auteurs (1, 6), la détermination de faibles quantités de magnésium, sous forme de pyrophosphate, donne des résultats erronés, le plus souvent trop élevés.

La précipitation du magnésium, sous forme de quinoléate de magnésium, par une solution alcoolique à 5% de 8-hydroxyquinoléine, donne des résultats beaucoup plus satisfaisants.

HISTORIQUE

Depuis une vingtaine d'années, les travaux sur le réactif 8-hydroxyquinoléine se sont multipliés. D'après Hoffman (3), le principe de la précipitation du magnésium par ce réactif fut utilisé par Hahn et adopté par R. Berg, en 1927, par C. BomsKov, en 1931, et par D. M. Greeberg et M. A. Mackay, en 1932. En 1934, Javillier et Lavollay (5) présentent un travail sur l'emploi de la 8-hydroxyquinoléine pour la détermination du magnésium. Plus près de nous, en 1938-39, Fr. Hormidas et Délorme (4) présentent à l'Office des Recherches Scientifiques de la province de Québec, le résultat de leurs recherches sur le calcium et le magnésium chez les végétaux.

D'après tous ces auteurs et beaucoup d'autres, la précipitation du magnésium sous forme de quinoléate, s'opère en milieu ammoniacal, en présence de chlorure d'ammonium. La présence de l'acide phosphorique et du magnésium du sol, peut fort bien, en milieu ammoniacal, donner naissance à un phosphate ammoniac-magnésien. Travailler dans un tel milieu peut occasionner des pertes de magnésium. Le fait a été constaté par Fr. Hormidas et Délorme (4). Aussi, certains auteurs éliminent-ils les phosphates avant la précipitation du magnésium.

Dans le présent travail nous contournons la difficulté en précipitant le magnésium, sous forme de quinoléate, en milieu sodique en présence de tartrate de sodium.

Comparaison de la méthode proposée avec la méthode au pyrophosphate.

Nous avons déterminé le Mg total sur quatre échantillons de sol. Après avoir fait les fusions en double selon la méthode officielle de l'A.O.A.C., on élimina la silice et ramena à un volume connu. Deux aliquotes de chaque sol servirent à la détermination du Mg en utilisant la méthode proposée. Les autres aliquotes, placées dans des fioles scellées, furent analysées selon la méthode officielle de l'A.O.A.C., cinquième édition, 1940. Voici les résultats obtenus (Tableau 1):

TABLEAU 1

Echantillon	Méthode proposée	Méthode au pyrophosphate
16503	2.05% MgO	2.20% MgO
16504	0.84% MgO	0.86% MgO
16505	1.14% MgO	1.34% MgO
16506	1.32% MgO	1.32% MgO

¹ Résumé d'une thèse de maîtrise présentée en 1942 à la Faculté d'Agriculture de l'Université Laval.

² Directeur du Département de Chimie et Physique agricoles, à la Faculté d'Agriculture de l'Université Laval, Québec.

³ Agronome-analyste au Laboratoire Provincial des Sols, de la Province de Québec, Ste.-Anne-de-la-Pocatière.

La méthode au pyrophosphate a donné des résultats légèrement supérieurs.

Comparaison de la méthode proposée avec les autres méthodes à la 8-hydroxy-quinoléine, opérant en milieu ammoniacal et en présence du chlorure d'ammonium.

Neuf portions de 25 gr. du même sol furent lavées chacune avec 1000 cc. d'acide acétique, N/2, selon la méthode décrite par Williams (7). Les neuf litres de la solution furent partagés en 18 aliquotes de 500 cc. chacune, correspondant à 12.5 gr. de sol.

Dans la méthode proposée et décrite plus loin l'acide phosphorique et le Mn ne sont pas éliminés avant la précipitation du Mg. En étudiant le Tableau 2, nous constatons:

(a) Que l'acide phosphorique du sol, en présence du Mg. et de NH_4OH , peut former un phosphate ammoniaco-magnésien, et par conséquent donner des résultats trop faibles;

(b) Que le Mg ajouté fut presque entièrement trouvé avec la méthode proposée.

TABLEAU 2

—	N°	Méthode proposée	N°	Autres méthodes
Dans 12.5 gr. sol	1	10.00 mgrs. de Mg.	10	9.76 mgrs. de Mg.
	2	10.17 mgrs. de Mg.	11	9.73 mgrs. de Mg.
	3	10.07 mgrs. de Mg.	12	9.44 mgrs. de Mg.
12.5 gr. sol + 1.00 mgr. de Mg.	4	10.95 mgrs. de Mg.	—	*
	5	10.95 mgrs. de Mg.	14	10.89 mgrs. de Mg.
	6	11.11 mgrs. de Mg.	15	10.94 mgrs. de Mg.
12.5 gr. sol + 2.00 mgr. de Mg.	7	12.00 mgrs. de Mg.	16	11.65 mgrs. de Mg.
	8	12.00 mgrs. de Mg.	17	11.84 mgrs. de Mg.
	9	12.02 mgrs. de Mg.	18	11.75 mgrs. de Mg.

* Perdu.

Il est à remarquer, en plus, que le Mn fut déterminé dans les précipités et les filtrats. Avec la méthode proposée, nous avons trouvé que le Mn ne précipite qu'à l'état de trace. Le reste se trouve dans le filtrat. En opérant en milieu ammoniacal, le Mn précipite totalement.

Description de la méthode proposée.

25 gr. de sol, séché à l'air, sont lavés avec 1000 cc. d'acide acétique N/2, selon la méthode de Williams (7). Le filtrat est évaporé à sec, calciné à 500° C. durant environ 30 minutes. Après la détermination des bases totales échangeables, on élimine le Fe et l'Al en les précipitant sous forme d'hydroxydes par NH_4OH (1 : 1), en présence de NH_4Cl et de méthyl rouge comme indicateur. Au filtrat légèrement acidifié par HCl dilué et porté à l'ébullition on ajoute un excès d'oxalate d'ammonium, puis quelques gouttes de bromo-phénol bleu; la solution se colore en jaune.

On ajoute goutte à goutte NH_4OH (1 : 1) jusqu'au virage violet très net, ce qui correspond à un pH de 4.2 à 4.6. On laisse refroidir et on filtre, en lavant à l'eau très chaude. En opérant dans ces conditions, il ne précipite pas de Mg et aucun sel alcalin n'est entraîné (2).

Le filtrat contenant le Mg est évaporé à sec. On ajoute 25 cc. de HNO_3 concentré, on laisse digérer pendant 12 heures, en recouvrant le bécher d'un verre de montre. On évapore à sec, calcine au four à 400°C . pour volatiliser les dernières traces d'ammoniaque.

Le résidu est dissous dans HCl dilué, traité par 75 cc. d'eau et 3 gr. de tartrate de Na, chauffé jusqu'au point d'ébullition, en agitant pour dissoudre le tartrate de Na. On neutralise par NaOH , 2N, en présence de méthyl rouge. On ajoute alors 5 cc. d'une solution alcoolique de 8-hydroxyquinoline, et, immédiatement, 15 cc. de NaOH , 2N. On recouvre le bécher d'un verre de montre et on le place sur un bain-marie à l'ébullition durant 45 minutes environ. On laisse alors refroidir et reposer durant 2 à 4 heures. On filtre dans des creusets de Gooch ou de verre Iéna. Le précipité est lavé à l'eau froide très légèrement ammoniacale (1 : 50), séché à l'étuve à 160°C ., pendant au moins 2 heures, refroidi et pesé. Le quinoléate de Mg obtenu contient 7.78% de Mg.

RÉSUMÉ

En présence de tartrate de Na et de NaOH , la précipitation du Mg peut s'effectuer quantitativement par la 8-hydroxyquinoline, en présence de l'acide phosphorique et du manganèse déplacés en lavant le sol par l'acide acétique N/2, ou tout autre acide dilué ou sel neutre employés pour le déplacement des bases échangeables du sol. Dans un tel milieu l'acide phosphorique n'a aucune influence sur la précipitation du Mg. Le Mn ne précipite qu'à l'état de trace, même pour des quantités relativement considérables.

BIBLIOGRAPHIE

1. ALEXANDER, O. S. and J. H. HARPER. Soil Sc. Am. Proc. 3 : 153-7. 1938.
2. BOLL, MARCEL, ET J. LEROIDE. Précis d'analyse chimique, II. 108. 1927.
3. HOFFMAN, W. S. Photometric Clinical Chemistry, 163-72. 1941.
4. HORMIDAS, FR. I. C., ET J. DÉLORME. Rapport complet des travaux de recherches sur le calcium et le magnésium dans les végétaux, soumis à l'Office des Recherches Scientifiques de la province de Québec. 1939.
5. JAVILLIER, M. ET J. LAVOLLAY. Bull. Soc. Ch. Biol., 16 : 1531. 1934.
6. METSON, A. J. Cawthron, Inst. Soil and Pasture, Res. Pub. 67, Wellington, N.Z. 1941.
7. WILLIAMS, R. J. Ag. Sci., 19 : 589-99. 1929.

RÉSUMÉ

Magnesium is precipitated quantitatively by 8-hydroxyquinoline in presence of sodium tartrate and sodium hydroxide. The presence of phosphoric acid and manganese that can be drained by washing the soil with acetic acid N/2, or any other diluted acid, or neutral salt which has been used to extract the exchangeable bases, does not affect the former precipitation. Only minute amounts of manganese can be detected in the precipitate even when a large quantity is present.

METHYL BROMIDE FUMIGATION OF PLANT PRODUCTS IN RAILROAD FREIGHT CARS WITH SPECIAL REFERENCE TO WORK SUPERVISED BY THE DOMINION DEPARTMENT OF AGRICULTURE DURING 1944¹

H. A. U. MONRO² AND R. DELISLE³

Dominion Department of Agriculture, Montreal, P.Q.

[Received for publication, July 9, 1945]

As a result of the finding of severe insect infestations in cargoes of plant products imported into Canada in the early part of the present war, the Division of Plant Protection, Dominion Department of Agriculture, was obliged in 1942 to institute a policy of inspecting such cargoes immediately on arrival in this country and insisting on treatment when considered necessary. A more detailed account of this situation, with the considerations of policy involved, was given by McLaine (4) in a review of the war activities of the Divisions of Entomology and Plant Protection since 1939. In brief, the object of this work is not merely to disinfest the imported goods themselves, but also to prevent the spread of the large insect populations involved to other commodities, during handling in steamship sheds, railroad cars, lake and canal steamers, trucks and terminal warehouses.

During the season of 1944 large bulk consignments of plant products arrived in this country in steamships. These importations were made exclusively by one agency, the Bulk Purchasing Division of the Commodity Prices Stabilization Corporation, which operated under the Canadian War-time Prices and Trade Board. The active co-operation of the officials of this organization enabled a considerable amount of preliminary arrangement to be made prior to the arrival of each shipment.

The activities of this Division in inspecting shipments and stipulating treatments had the effect of bringing the value of this type of control to the attention of representatives of food distributing organizations and transportation companies. As a result, our inspectors were asked to supervise the treatment of export shipments of foodstuffs, notably consignments sent by the International Red Cross to distressed European countries. Strictly speaking, this activity lay outside the scope of duties originally envisaged for this organization, but the work was gladly undertaken to ensure that all food reaching such countries should be as free as possible from insects liable to cause deterioration.

All the treatments were carried out by qualified pest control operators or concerns expert in industrial fumigation, working under the supervision of our inspectors.

The majority of the treatments were made in railroad cars, and the fumigant used was exclusively methyl bromide. This paper, therefore, deals with a discussion of the railroad car fumigations and the use of methyl bromide as a fumigant in this technique.

¹ Contribution No. 47 from the Plant Protection Division, Science Service, Department of Agriculture, Ottawa, Ont.

² Supervising Inspector in Charge of Fumigation, Division of Plant Protection, Montreal, P.Q.

³ Inspector, Division of Plant Protection, Montreal, P.Q.

GENERAL ORGANIZATION

With the exception of two cargoes which arrived at New York, all the import shipments were unloaded at Canadian ports. The latter were inspected immediately on docking by officers of this Division, and arrangements were also made for one of our inspectors to examine on the dock a cargo of peanuts unloaded at New York. One lot of cotton seed meal shipped through New York, reached the ultimate consignees at different points in Canada before severe infestation by the cigarette beetle, *Lasioderma serricorne*, F. was detected.

For the most part the district inspectors were advised well in advance of the arrival of the steamers and, acting on the assumption that such commodities as peanuts would be infested, as they invariably were, made plans for their handling and treatment. The arrangements consisted, for the most part, in ensuring that the railroad company had an adequate number of suitable steel box cars on hand and in seeing that well qualified fumigators were available with supplies of the fumigant.

If the consignment was found to be so infested that treatment would be required, the importer was informed immediately, as among other considerations, the work would be done at his expense. The importer and the transportation company responsible for moving the goods inland having already decided if the treatments were to be made at the port of arrival or at final destination, arrangements were completed with the fumigators concerned. During 1944, both methods were tried, i.e. by fumigating the railroad cars containing the goods before they left the seaport or by delaying treatment until the cars arrived at or near destination. As far as this division was concerned, it was greatly preferable for the work to be done at the port of arrival. In actual practice, too, this was found by the railway companies to be the most convenient method and will probably be followed more closely in the future.

For the most part the cars employed were of 3,710 cubic feet capacity and were usually loaded with 400 to 500 bags of commodities such as peanuts or chick peas, a total commodity weight of approximately 70,000 to 90,000 pounds.

The loaded railroad cars were diverted, as far as possible, to isolated yards remote from human habitation where four or more tracks were available for holding the cars during treatment and aeration. It was found desirable to segregate the cars undergoing aeration on a special "ventilation" track, so that the fumigating crews preparing the next batch of cars for treatment would not be exposed to the gases diffusing from those being aired out.

In theory, the inspectors left the carrying out of the treatments to the fumigators, the acceptance of each individual treatment being based on the examination of the cars after aeration. In practice, however, the experience of the inspectors was drawn upon, when required, to advise the fumigators on methods. After completion of the inspection, those cars found to be satisfactorily treated were released for dispatch to destination, while in the small percentage of cases of failure, repetition of the treatment was required. In some cases this involved a more careful sealing of the car or transfer of the goods to a more satisfactory car.

COMMODITIES TREATED AND INSECTS INFESTING THEM

The commodities treated, both for import and export, are summarized in Table 1. A short description of the various commodities, with the insects infesting them, is also given herewith.

Imports

Broom corn: Importations of broom corn from countries other than the United States of America are subject to a quarantine treatment under the provisions of the Destructive Insect and Pest Act irrespective of the finding of infestation or not. This work is usually done by vacuum fumigation at Montreal. In February, 1944, however, an exceptionally large consignment of 6,127 bales was imported in bulk from the Argentine for general distribution in this country. In view of the large size of this shipment, which would take 3 or 4 months to pass through the vacuum vault, and the fact that the large amount of extra handling involved in stopping the goods at Montreal was to be avoided under wartime conditions, a special experimental project was undertaken whereby a method was worked out for treating the broom corn at temperatures between 30 and 40 degrees F. in steel box cars at the point of unloading. This is being made the subject of a separate report.

TABLE 1.—SUMMARY OF BOX CAR FUMIGATIONS SUPERVISED DURING 1944

Name of port or district where treatment carried out	Imports			Exports			Totals	
	Commodity	Weight in short tons	No. of cars	Commodity	Weight in short tons	No. of cars	Weight in short tons	No. of cars
Halifax, N.S.	Cotton seed meal	60	2	Chicory root	45	2	105	4
Saint John, N.B.	Broom corn	1,063	94	Mexican chick peas Wheat	2,106	63	10,129	340
	Indian peanuts	180	5		3,282	81		
	Indian peanuts	3,498	97					
Quebec, P.Q.	Nigerian peanuts	112	7				152	8
	Cotton seed meal	40	1					
Montreal, P.Q.	Nigerian peanuts	3,948	95				9,232	216
	Indian peanuts	4,150	94					
	Nigerian peanuts	1,134	27					
Toronto, Ont.	Nigerian peanuts	1,455	67				5,936	175
	Indian peanuts	4,309	105					
	Cotton seed meal	172	3					
London, Ont.	Nigerian peanuts	907	33				907	33
Vancouver, B.C.	Indian peanuts	4,341	97				4,341	97
		25,369	727		5,433	146	30,802	873

Peanuts: Large consignments of British Indian and Nigerian shelled peanuts arrived in seven steamers during 1944. These were all found to be severely infested at the time of unloading with the following species of insects:

- COLEOPTERA *Tribolium castaneum* Hbst., Red flour beetle
Dermestes ater De G. = *cadaverinus* Fab.
Tenebroides mauritanicus Linn., the Cadelle
Necrobia rufipes De G., Red legged ham beetle
Oryzaephilus surinamensis L., saw-toothed grain beetle
- LEPIDOPTERA *Ephestia sericarium* Scott = *kuehniella* Zell., Mediterranean flour moth
Corcyra cephalonica Staint. The rice moth
Plodia interpunctella Hbn., Indian meal moth (in shipment of Indian peanuts at Vancouver only)

Cotton Seed Meal: A shipment of approximately 1,000 tons of cotton seed meal in bags was made from Brazil to Canada in the late spring of 1944. This shipment came direct by rail via an United States port and was transported to a number of consignees throughout Eastern Canada. Several consignees refused to accept this material into their warehouses on finding a large number of insects, subsequently identified chiefly as larvae of the cigarette beetle *Lasioderma serricornis* F., with a few adults of *Tribolium castaneum* Hbn. present also. The matter was brought to the attention of our District Inspectors and it was decided that all the material not as yet consumed should be treated to prevent the spread of the infestation. Several warehouse fumigations with methyl bromide were made on material all ready unloaded on the premises of the consignees, with good results. A number of railroad car fumigations were also successfully carried out.

Exports

Chick Peas: In late April, 1944 at Saint John, N.B., portions of a large shipment of chick peas ("Garbanzos", the seeds of *Cicer arietinum*), en route to Greece through the agency of the International Red Cross, were found by our inspectors to be infested by the cow pea weevil *Callosobruchus maculatus* Fab. (*Mylabris quadrimaculatus* Fab.). These peas had been grown in Mexico and were a gift of the United States Government to the people of Greece. As mentioned before, this Division had no direct jurisdiction over this material, but, in view of the nature and destination of the consignment, gladly co-operated by loaning the services and technical experience of the Saint John staff for the supervision of the fumigation of those carloads of peas found to be infested as they arrived at Saint John. In treating this shipment a considerable amount of reloading had to be carried on in order to transfer the bags to Canadian steel box cars from the original cars, which belonged to United States railroads and were largely of wood construction or were otherwise unsuitable for fumigation.

Wheat: In September, 1944 a shipment of wheat grown in the United States and en route to the British authorities in France via Saint John, N.B., was refused for loading on board the steamer by the steamship agents, following the finding of an outbreak of *Plodia interpunctella* in parts of the consignment, which was packed in 100-pound bags. Our inspectors were again asked to supervise the fumigation work. In this case, also, a considerable amount of reloading of cars had to be undertaken.

Chicory Root: A shipment of 1,046 bags of chicory root on the way from Montreal to Iceland in November, 1944 was found, at the time of loading at Halifax, to be infested with *Plodia interpunctella* Hbn. This material was fumigated in two steel box cars, the interesting aspect of this work being the low temperature at which the treatment was carried out and which will be fully described under "Results."

STEEL BOX CAR CONSTRUCTION AS EFFECTING FUMIGATION WORK

The use of methyl bromide in Canada for fumigating goods in steel box cars was first discussed by Monro and Delisle (5). As was to be expected, it was subsequently found that the success of the treatments depended greatly on the construction of the individual cars, especially in the structure and method of attachment of the roofs. As a result of observations made on the construction of steel box cars during a large number of fumigations, and following consultation with the officials of the mechanical departments of the two principal Canadian railway companies, it has been possible to prepare lists by number series of preferred classes of steel box cars most suitable for fumigation work, in view of their being sufficiently air tight not to require sealing other than at the doors. As a matter of general policy wooden box cars are not permitted to be used, although in exceptional cases, these have been successfully employed. (During the severe steel shortage a few plywood box cars of design similar to recent steel box cars were constructed by the Canadian Pacific Railway Company, as illustrated in Figure 1. These proved to be in every way as good as steel box cars for fumigation purposes.)

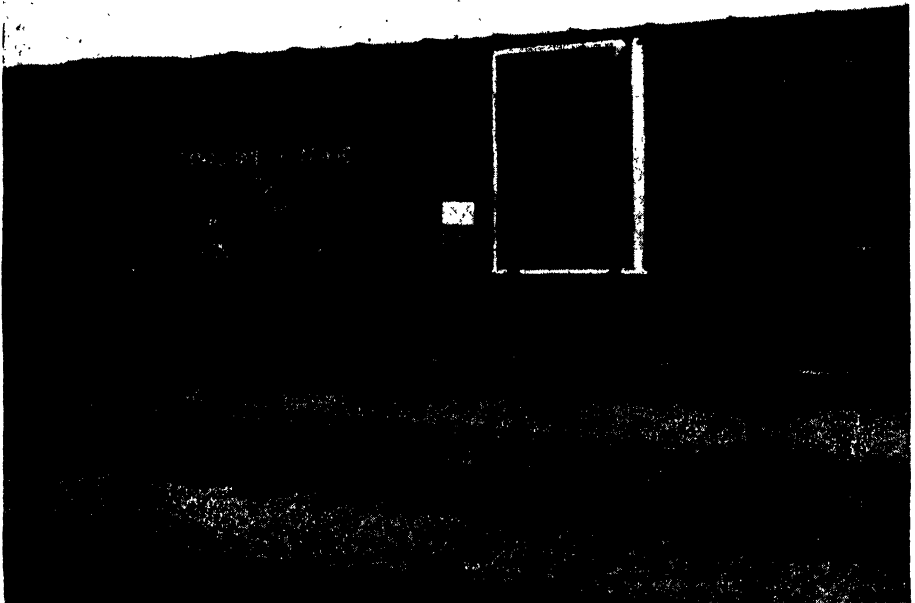
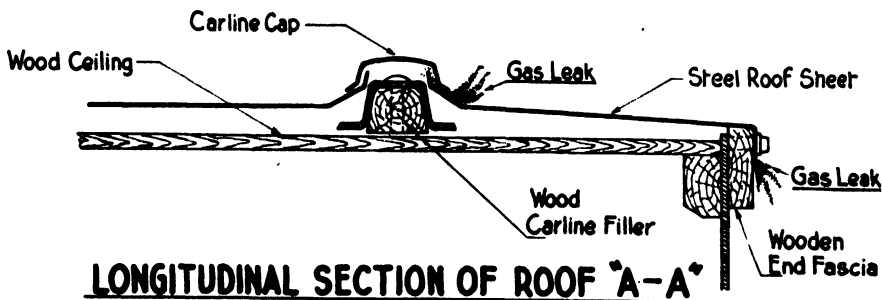
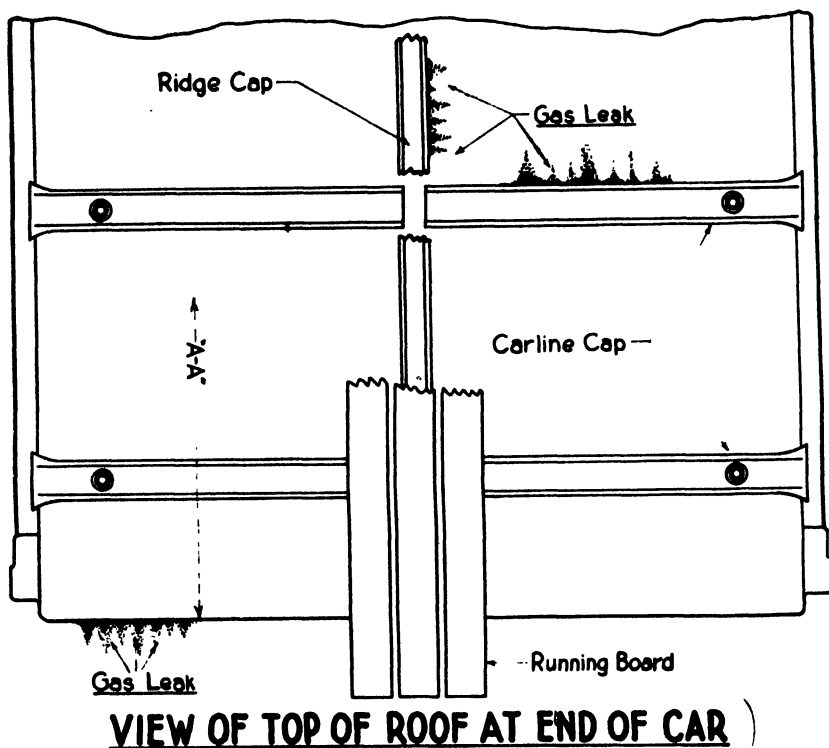


FIGURE 1. Canadian Pacific Railway freight car with plywood walls and steel roof. (Authors' photo).



CANADIAN NATIONAL RAILWAYS **DRY LADING ALL STEEL ROOF** **BOX CAR NUMBERS 471000-473999**

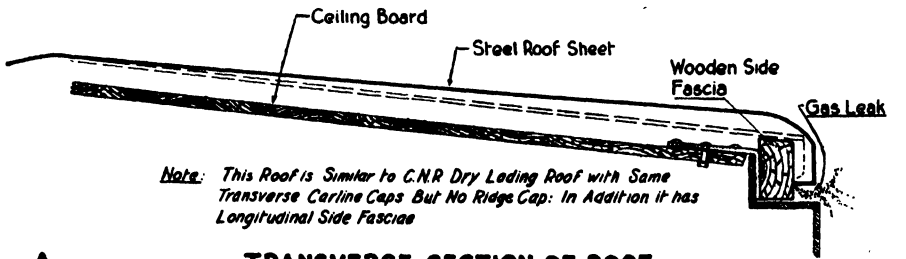
H. G. Carmody 45

FIGURE 2

In "steel" box cars the walls and roofs are made of steel, but the floors are constructed with boards, usually British Columbia fir, 4 inches wide and $2\frac{1}{2}$ inches thick, joined by tongue and groove. Leaks of fumigants do not usually occur through the floors.

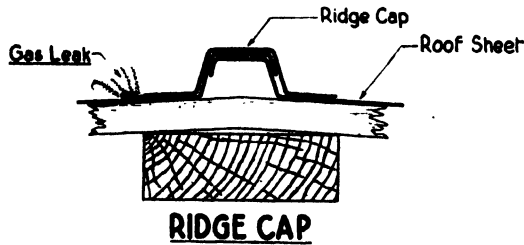
As a general rule, the air-tightness of a steel box car deteriorates with age, as constant vibration enlarges seams and cracks in the walls and roofs. It is therefore desirable to rule out, as far as possible, steel box cars more than 15 to 20 years old. Canadian steel box cars constructed approximately between 1927 and 1940 were equipped with types of all steel roofs known principally as "dry lading" or "radial" roofs.

These roofs, by the nature of their construction and the method of their attachment to the walls of the cars, will permit a considerable amount of leakage. The three types of roof construction encountered in these classes are illustrated diagrammatically in Figures 2 and 3. The Canadian National Railways "radial" roof has transverse carline caps and a longitudinal ridge cap at the point of junction of the steel roof plates. At each end of the car, also, the end plate is bolted over a wooden sill or "fascia."



A

TRANSVERSE SECTION OF ROOF
ALL STEEL RADIAL ROOF



B

LONGITUDINAL SECTION OF ROOF AT END OF CAR
FLEXIBLE NO. 2 PIVOTED ROOF

CANADIAN PACIFIC RAILWAY

BOX CAR NUMBERS 225000-225699 } ROOF TYPES A. & B.
240000-247499 } PRESENT IN BOTH SERIES,
BUT MOSTLY A.

H.A. Cermody '45

FIGURE 3

At both these points continual leakage of methyl bromide has been observed.⁴ The "dry lading" steel roof of the Canadian Pacific Railway cars has transverse carline caps at the junctions of the steel plates, but these latter extend the full width of the car, and there is therefore no longitudinal ridge cap. This latter advantage is offset, however, by the fact that the roof rests on wooden fasciae at both sides and ends.

These roofs are also illustrated in photographs of the box cars in Figures 4 and 5. With continued wear and tear, warping and displacement



FIGURE 4. Older type Canadian National Railways steel freight car with wooden "fascia" at end of roof.

of the steel plates and the wooden fasciae occur to aggravate the amount of gas leakage. Pest control operators state that an additional four or five man-hours of work in sealing these cracks are required to render the cars fit for a satisfactory fumigation. As far as possible, the co-operation of the railway officials is solicited to avoid the use of these types of cars for conveying infested commodities requiring treatment (see Table 2).

The Canadian Pacific Railway "pivoted" roof (B in Figure 3) has never been encountered on all steel cars, although officials state that it is employed. It is common on wooden box cars with steel roofs. The great

⁴ All these points of leakage were first demonstrated in actual practice during fumigations with methyl bromide with the aid of the commonly employed "Halide Leak Detector," various types of which are manufactured and marketed by different companies.

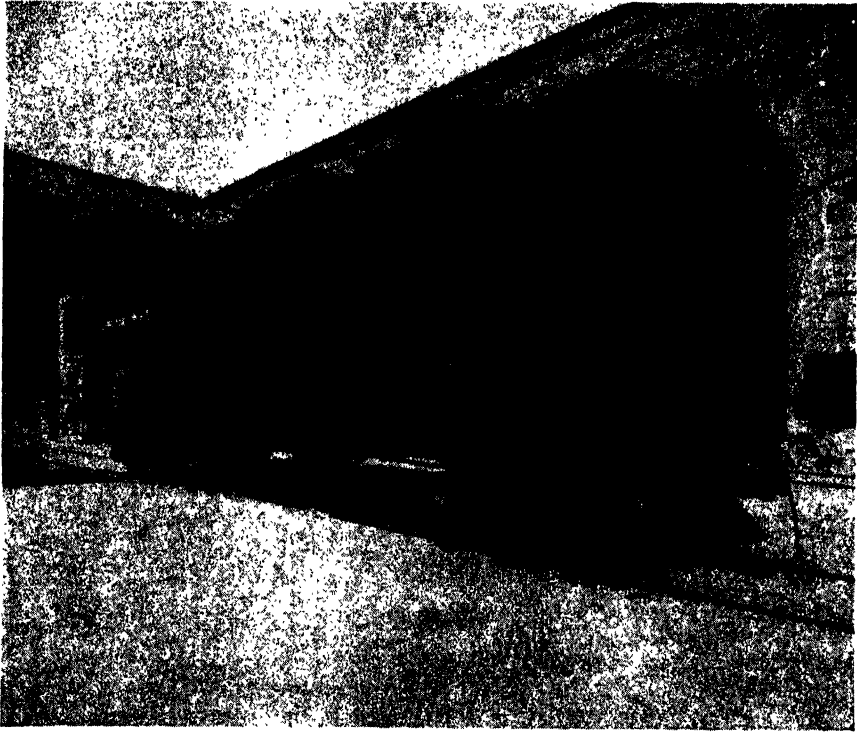


FIGURE 5. Older type Canadian Pacific Railway steel freight car with wooden "fasciae" at end and sides.

possibility of leaks through the intermediate transverse caps, which could not be easily sealed off, would seem to rule out from the beginning box cars so equipped.

TABLE 2.—CLASSIFICATION OF CANADIAN FREIGHT CARS

Listed by number series according to suitability for fumigation.

A. CARS WHICH SHOULD NOT BE EMPLOYED

- (1) *All Wooden Box Cars.* (Some wooden box cars have been successfully employed, but a definite rule must be laid down to avoid them.)
- (2) *All Automobile Cars.* (Even with considerable extra sealing, failures must be expected with this type.)

B. STEEL BOX CARS WHICH SHOULD BE AVOIDED, IF POSSIBLE, OWING TO CONSIDERABLE EXTRA SEALING REQUIRED

These cars have wooden sills (fasciae) at junction of wall and roof.

CANADIAN NATIONAL RAILWAYS

471000 – 473999, flexible all steel radial roofs.

CANADIAN PACIFIC RAILWAYS

225000 – 225699, flexible or pivoted steel roofs.

240000 – 247499, flexible or pivoted steel roofs.

C. CARS WHICH CAN SAFELY BE EMPLOYED

CANADIAN NATIONAL RAILWAYS

474000 - 487764, plus new cars, riveted and welded steel roofs.
520000 - 521999, 50-ton capacity cars with riveted steel roofs.

CANADIAN PACIFIC RAILWAYS

221000 - 224449, riveted and welded steel roofs and plywood sheathed cars.
226000 - 228799, riveted and welded steel roofs.
248350 - 251249, plus new cars, riveted and welded steel roofs.

In recent steel freight car construction, mostly during the last four or five years, both Canadian railway companies have employed all steel roofs, described either as the "riveted roof" or "solid steel roof." An example of this roof is illustrated in Figures 6 and 7. The steel plates are riveted or welded together and the seams filled with a caulking compound. The entire roof is then riveted and caulked onto the walls, so that an airtight structure is produced. The number series of these new types (to recent date) are given in Table 2. These cars are so well made that they form perfect fumigation structures and, if thoroughly sealed, the amount of gas leakage from them appears to be practically nil, so that a constant minimum dosage can be safely employed.

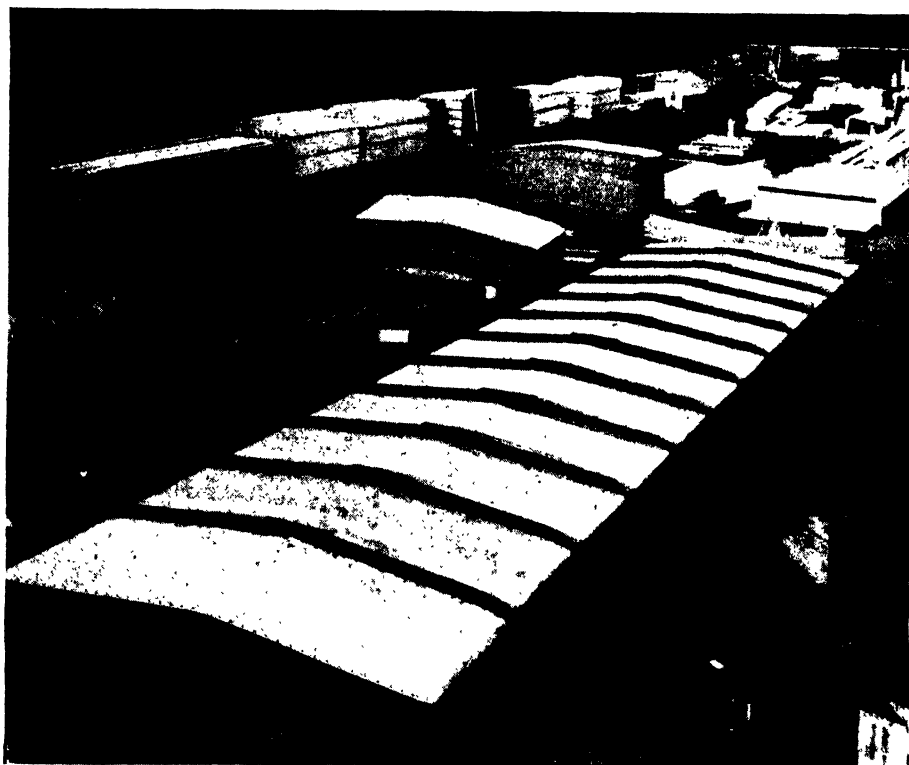


FIGURE 6. New type riveted steel roof as used on Canadian National Railways steel freight car (see Figure 7).

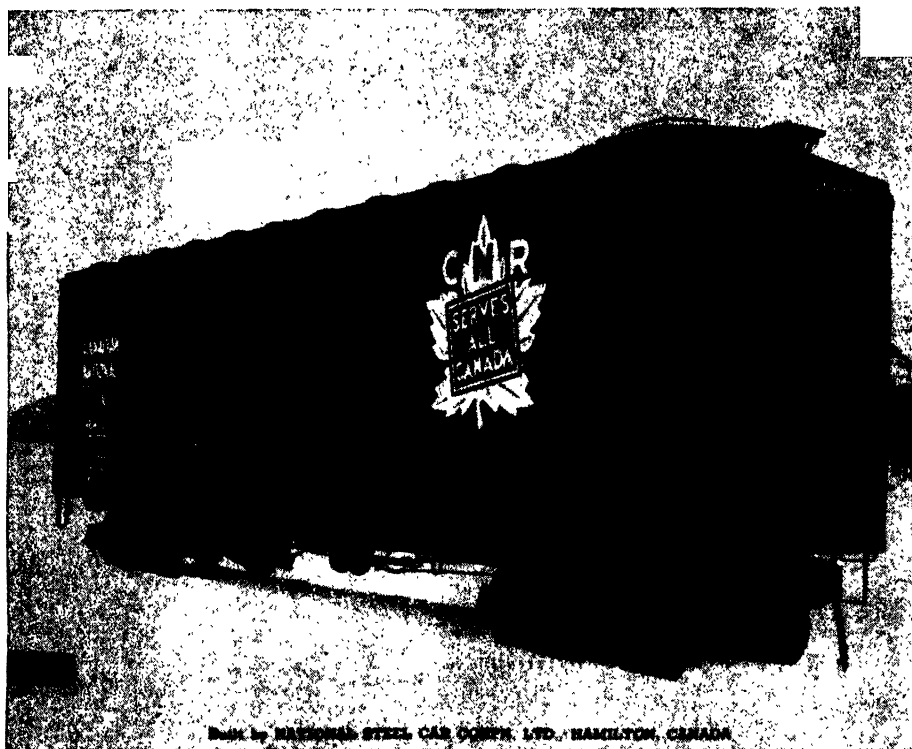


FIGURE 7. New type steel freight car with all steel roof.

In our experience steel freight cars owned by railways in the United States and which have been used while in Canada have not, on the average, been so suitable for this type of work. This has been due, for the most part, to the fact that American cars seen in this country have been both considerably older, dating many of them prior to 1929, and subjected to more wear and tear. A number of recently built cars, similar to the Canadian all steel car with the riveted roof, have been encountered, proving to be as suitable as the most recent Canadian types.

FUMIGATION METHODS

Fumigant Employed

In all this work methyl bromide was the fumigant employed, either alone or in combination as a proprietary fumigant containing approximately 93% carbon dioxide and 7% methyl bromide.

Methyl bromide (CH_3Br) at ordinary temperatures is an odourless gas, boiling from a colourless liquid at 40.1°F . and having a specific gravity (Air = 1.00) of 3.27 at 32°F . It is thus considerably heavier than air. The molecular weight is 94.94. Experience has shown that it tends to stratify if introduced at the lower part of a fumigation structure, but once thoroughly mixed with air by fan circulation or diffusion it remains in equilibrium with all parts of the atmosphere of the structure. It is lost very rapidly through any point of leakage.

• Methyl bromide alone is supplied in 1-pound cans or cylinders of different weights. When mixed with carbon dioxide it is usually marketed in cylinders containing 50 lb. of the mixture.

The natural vapour pressure in methyl bromide containers is: at 50° F.—4 lb. per square inch; 60° F.—8.5 lb.; 70° F.—13 lb.; 80° F.—19 lb.; 90° F.—25 lb.; 100° F.—32 lb.

Sealing the Cars

In box car fumigation considerable care and thought must be given to the extra sealing required, to prevent avoidable leakage of the gas. Methyl bromide is very volatile and quickly diffuses through any leaks in the structure. As already pointed out, in the best type of steel box cars sealing in the region of the doors is all that is required.

Experience has shown that the best method is to seal both doors from the outside, so that every point of leak detected round the sealing is accessible after sealing is completed. Many insects attempt to escape from the gas by crawling into cracks in the floor and under the door, and outside sealing ensures both that the fumigant is able to penetrate these cracks and also that the insects are unable to reach the outside air. In addition to sealing round the doors it is also necessary to seal off small leaks around the rollers of the door tracks. Other points of leak may be encountered from time to time, such as rain drainage outlets found in some types of cars.

Under normal conditions effective sealing can be done with brown paper liberally smeared on both sides with a good quality casein paste or one containing a mixture of flour and oil. A sticky mineral jelly such as vaseline (petrolatum) has been used to stick down the paper, and this is especially useful at lower temperatures, but it is necessary to wipe the surface afterwards to remove the jelly to prevent accidents liable to be caused by the slippery surface. Other methods have been successfully employed at the discretion of the individual operators, including the use of a mixture of calcium chloride and asbestos.

Before the war masking tape was usually recommended for convenience, but at the time of writing it is difficult to obtain.

Applying the Fumigant

As the whole treatment was placed in the hands of the commercial operators, the methods of applying the fumigant were left largely to their individual choice. Actually, for the reasons discussed hereafter, this Department would prefer the employment of a method by which the gas is applied from outside the car.

"Cold Gas" and Pan Method: The methyl bromide in 1-pound cans is cooled off with dry ice until it is at a temperature well below its boiling point. Two operators, wearing gas masks and either leather or rubber gloves then enter the car through one door, the opposite door having already been sealed either on the inside or, preferably, the outside. Each man working from one end of the car, the cans are opened with special openers ("beer can openers") and the contents poured into shallow dishes or baking pans, placed at intervals on top of the bags, until the required

dosage is obtained. The open door is rapidly closed and sealed after the operators withdraw (Figure 8). This method has been found very effective for obtaining complete control of the insects as long as the pans are placed near the highest points of the bags. Apparently the majority of the gas



FIGURE 8. Sealing freight car after application of fumigant.

remains for some time at a low level in the cars, as failures have so far not been reported in the cars with the wooden fasciae described above. Unfortunately, the cooled cans are too cold to be carried in the bare hand and, when gloves are worn by an operator treating a fair number of cars per day for several continuous days, typical "methyl bromide" blisters develop on the thumbs and fingers of the men. These are irritating and take some time to heal up. The formation of these blisters is due to the absorption and retention of methyl bromide in the fabric of the glove.

"Hot Gas" Method: In this case the procedure is similar to that in the foregoing method, but the cans are not cooled and the operator does not usually wear gloves. Usually, also, pans are not used, but if they are they merely serve as a platform on which to set the cans. The cans are opened with can openers or sharp chisels, and immediately a mixture of gas and liquid is forced out of the can, and on warm days this effect is greatly increased. It is impossible to avoid the spilling of some of the liquid on the fingers and here again blisters develop on the hands if more than a few cars are treated. Some operators prop the cans carefully between two bags, others merely stand at the door and throw them towards the end of the cars.

• With this method serious leaks of fumigant and failures to obtain control have resulted when used with cars equipped with the roofs balanced on the wooden fasciae, and extra sealing is required to avoid this. Moreover, with the leak detectors tests have shown that some methyl bromide is lost to the open air before the open door can be shut. This method, therefore, is open to very serious objections and should be avoided, especially when a large number of cars are undergoing treatment.

"Can and Applicator" Method: Special applicators (see Figure 9) can be obtained for discharging methyl bromide from the 1-pound cans. By means of a steel spring which binds the can, a pointed steel tube surrounded

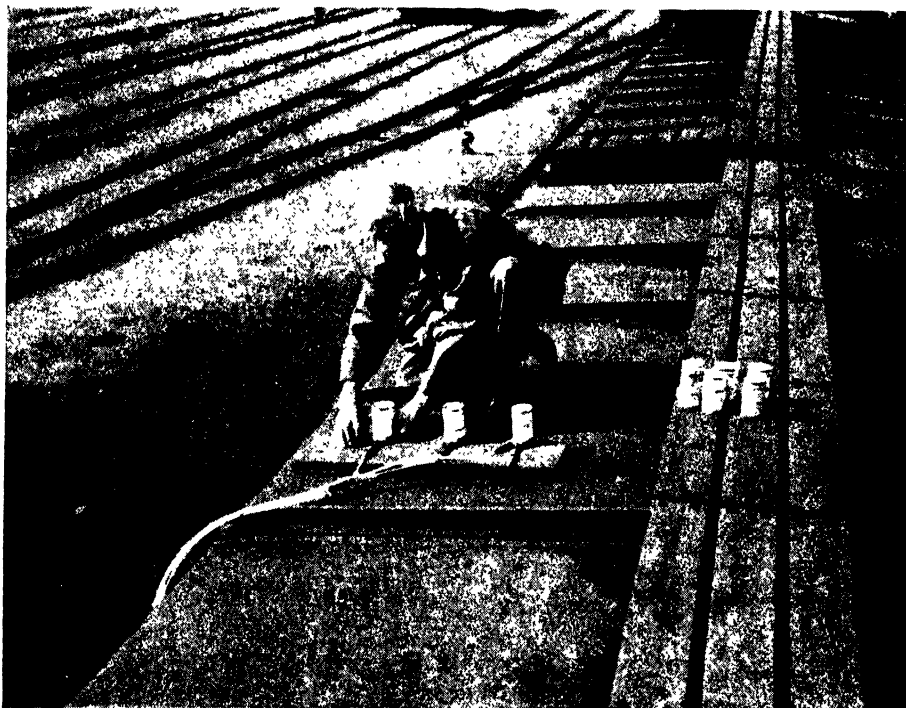


FIGURE 9. Use of methyl bromide cans to apply fumigant from a roof, especially useful in cool weather. (Authors' photo).

by a rubber gasket is thrust into the can and the liquid forced out by the gaseous pressure inside the can. Recently "Saran" plastic tubing has been introduced for carrying the fumigant to the point of discharge. These tubes are closed at the end with a copper thread and have small holes punched near the tip to allow the lateral discharge of the fumigant.

As illustrated (Figure 9) a convenient method of using this apparatus is to mount three applicators on a small wooden platform to steady the cans against the back pressure of the gas. If the cans are discharged from the top of the car residual gas and liquid in the line drains off more readily, especially in cool weather. One operator devised a method (see Figure 10) of holding the door practically closed by means of a wooden board 4 inches

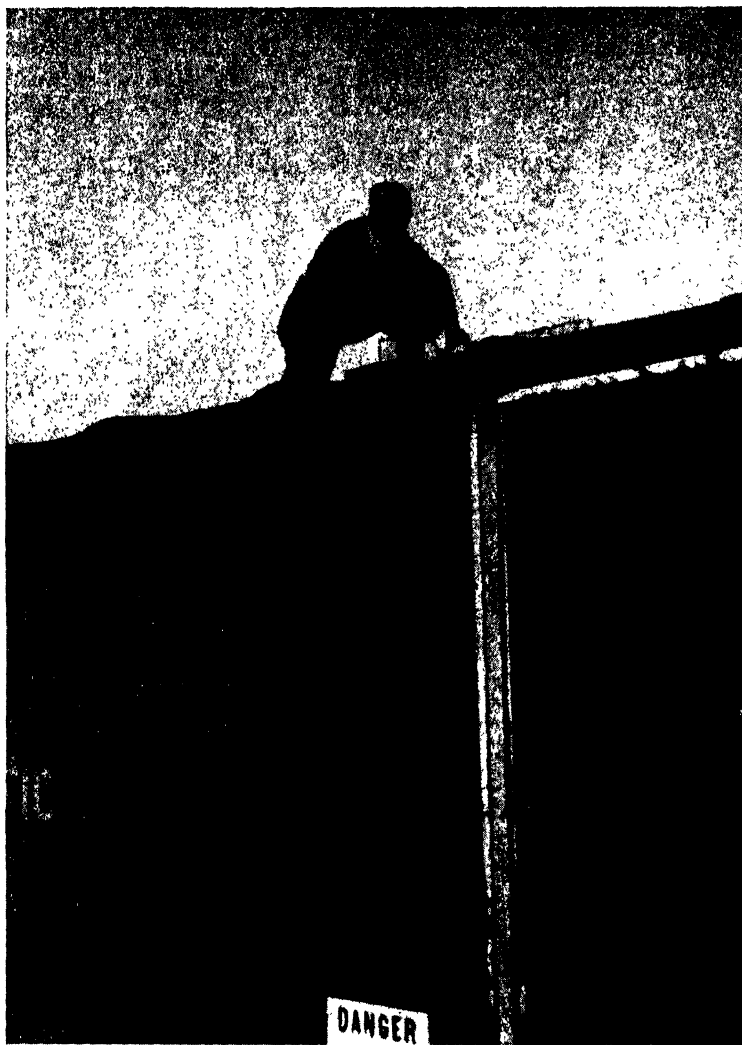


FIGURE 10. Roof application of methyl bromide, showing position of board in door. (Authors' photo).

wide placed in the door jamb, leaving a small aperture 6 by 4 inches in area at the top through which the tubes led into the car. The door could then be quickly sealed after the removal of the board.

Saran plastic tubing becomes somewhat brittle when cooled to about 32° F., and it is invariably cooled by the methyl bromide vapour discharging through it. Some care, therefore, must be exercised in handling it under these conditions.

Cylinder Methods: The unmixed methyl bromide can be very readily discharged from cylinders by the positive pressure of the fumigant itself, which is usually increased by the addition of some air before shipment.

By attaching an ordinary copper tube of, preferably, 3/16-inch internal diameter directly to the cylinder (Figure 11) the gas can be carried into the car through a small hole bored in the floor near the door or through the aperture above the board as described in the preceding section (Figure 10).



FIGURE 11. Cylinder method of methyl bromide application. (Authors' photo).

After discharge the hole in the floor should always be carefully filled with a hardwood plug whittled to the correct size. The copper tube should be pinched at the end and several small holes punched near the tip for side delivery of the fumigant. The weight of fumigant required is easily read on the scale holding the cylinder.

In many ways this is the most satisfactory and safest method of discharging the gas, and is the one preferred for recommendation by this

Division. However, operators have found the cylinders and scales heavy and awkward to move around in a railway freight yard, and, during recent years, there has been a shortage of cylinders.

The proprietary fumigant "Proxate" is discharged from 50-pound cylinders containing approximately 3.5 lb. of methyl bromide and 46.5 lb. of carbon dioxide. It is claimed that the carbon dioxide adds to the effectiveness of the fumigant, permitting lower doses of methyl bromide. This effect has never been confirmed by us in practical application, but there is no doubt that the carbon dioxide aids in the rapid diffusion of the toxic agent. However, in cars which are liable to leak, especially through the roof, failures have been recorded. This matter is discussed more fully under "Results." "Proxate" is usually discharged through holes bored in the floor of the car, so that both doors can be fully sealed before application. In very tight cars this fumigant mixture can often be observed discharging excess pressure by distending the paper sealing material, and thus sometimes some re-sealing is required. The entire contents of the two cylinders are discharged for each car, giving a dose of approximately 7 lb. of methyl bromide per car.

VENTILATION AND INSPECTION

The fumigation treatments were invariably made overnight, with exposure periods of 16 to 24 hours. At the end of treatment both doors were opened wide and the cars were not entered for at least two hours. Under most summer conditions this was sufficient for the dissipation of the gas from the body of the car, and only mild reactions for methyl bromide of approximately 50 parts per million were recorded among the bags towards the end of the cars. As might be expected, weather conditions influenced the ventilation of the gas considerably, and a number of different effects were observed, the more important of which are listed herewith:

(1) On warm windless days the gas dissipated rapidly from all parts of the cars and most quickly in the absence of extensive cloud cover.

(2) On very windy days, either cold or warm, when a strong draught of air crossed the middle of the cars, the gas was sometimes "pocketed" at one or both ends of the cars.

(3) In cool damp weather and during rain the gas took often considerably more than 6 hours to dissipate completely from the free air space in the cars. In Vancouver, B.C., during the night October 2nd to 3rd, rain and fog was continuous and there was no wind. A car of peanuts under observation was opened up at 2.00 p.m. on October 2nd when the outside air temperature was 56° F. and that in the free air space of the car 62° F. During the night these fell to 58 and 53° F., respectively and rose to 59° in both cases when due for inspection at 2.00 p.m. on October 3rd. The temperature in the peanuts was 65° F. 22 hours after opening. At this time the rain and fog were still prevailing. Tests with the leak detector showed methyl bromide present in the free air of the car to be 35-50 parts per million only 4 to 6 feet back from the opened doors, 24 hours after both doors had been opened.

The above examples demonstrate most forcibly the danger of following any hard and fast rules for natural ventilation. Climatic conditions, with their attendant air currents, have a very marked and variable effect. The

inspectors of this Division have instructions to protect themselves with careful and frequent use of the leak detector before entering cars to carry out inspections, as it is not considered practical or necessary for them to wear gas masks for this work. In practice, the examination of the commodity for insect kill is usually made at or near the doors, as these are the weakest points in the fumigation structure.

In no instance were the cars released for dispatch for destination until they had received at least 6 hours of continuous ventilation.

During 1944 each car of produce was examined by an inspector of this Division before being released. Some samples of peanuts from each consignment were also taken before and after treatment for checks on quality and residue. These matters are discussed further under "Results."

RESULTS

During 1944 a total of 873 freight cars were fumigated with methyl bromide under the supervision of this Department (see Table 1). Of this number 94 were cars of broom corn treated at low temperatures and in which only test insects were employed to estimate the mortality obtained. The broom corn treatments are being made the subject of a separate report.

Mortality of Insects

Of the balance of 781 cars which were used to treat peanuts, chick peas, wheat and cotton seed meal only 15 treatments were rejected for failure to produce a satisfactory kill of the insects found in the produce.

In assessing a "satisfactory kill" the inspectors were, theoretically, allowed to exercise some judgment. For example, the finding of one or two live insects in a heavily infested carload would not necessarily cause a rejection. In practice, however, rigorous inspection of the cars usually failed to reveal any living insects after the successful treatments. In the case of the failures, numerous survivors were always found.

In warm weather the insects were sometimes found in considerable numbers on the outside of the roofs and walls. These insects could, and did, migrate back into the cars during the ventilation process. Also, occasionally, insects were found flying from cars awaiting fumigation, and undergoing sealing, to cars being ventilated on an adjacent track. These movements back into ventilated cars seemed to be confined to a very small number of individuals and were of no consequence as they were not responsible for any fresh outbreaks of the pests.

On arrival of a few of the cars at destination complaints were made by the consignees following the finding of live insects on the commodity. On investigation it was found that only a few insects were involved and apparently they had moved back into the fumigated cars in the manner described above.

Cotton seed meal tends to pack very thickly in the bags, and it was thought that some difficulty might be encountered in gaining penetration. However, with a dose of 2.5 lb. per thousand cubic feet and a 36-hour exposure at summer temperatures complete control was obtained in the cars.

The record of 15 failures includes 13 due to unsatisfactory cars, a situation which, in view of wider experience, could be avoided by additional sealing of those cars which can be made more airtight or by rejection of cars now known to be structurally unsuitable for fumigation under any circumstances. The two failures due to faulty method came about through the use of the 1-pound cans and the Saran plastic tubing by an operator who was not familiar with their use. Here again additional experience will obviate such failures.



FIGURE 12. Freight car loaded with peanuts, after fumigation.

From 53 of the cars of peanuts successfully fumigated and passed by our inspectors at Montreal (43 cars) and Vancouver (10 cars) 2-pound samples of peanuts were taken to the laboratory and incubated at 80° F. and 60% relative humidity, suitable for rapid development of the species involved. These samples were examined periodically and in only three cases were insects found to develop. Two were from United States cars of doubtful construction treated with the proprietary mixture, and showed a development of *Tribolium castaneum* Herbst. The other was a sample from a sound car treated at Vancouver which showed complete mortality of all stages of *T. castaneum* and eggs and larvae of *P. interpunctella* but in which the only cadelle larva (*T. mauritanicus*) found was a survivor. Control samples removed before treatment showed continued development of the populations. These results coupled with observations made during unloading and storage tend to show that all stages of the insects listed above can be killed during a successful freight car fumigation in a satisfactory type of car.

Effect of Dosage

As already stated, the dose of fumigant and the methods of applying it were left to the judgment of the individual pest control operator. At the beginning of the project, when less was known about the sources of leak and the methods of overcoming them, an over all dose of 10 lb. of methyl bromide for a car of 3,710 cubic feet capacity (approximately 2.5 lb. per thousand cubic feet) was made for treatments with the temperature above 60° F. in both commodity and free air space. With the cars of the best type, as described above, it was found that 6 lb. per car was sufficient to give a complete kill (approximately 1.5 lb. per thousand cubic feet). Very few treatments were made at lower temperatures, but the operators concerned added $\frac{1}{2}$ pound per thousand cubic feet for every 5-degree drop below 60° F., based on the temperatures at time of application. These doses were usually employed for an exposure of 16-24 hours except in the cars of the cotton seed meal where a 36-hour exposure was given.

Effect of Temperature and Outside Weather Conditions

During the period May to November, 1944, a fairly wide range of temperature conditions was encountered. The lowest temperatures were experienced during the treatment of chicory root to control *Plodia interpunctella* larvae at Halifax on October 30. The temperatures experienced were: Commodity 46-50° F.; in free air of car 32° minimum during night, 50° maximum during day; in outside air 38° maximum, 24° minimum during the night. The period of exposure was 21 hours and the dose of methyl bromide 3 lb. per thousand cubic feet. Careful examination revealed that complete control of all the larvae had been obtained, including those boring deeply into the roots. In the fumigation of peanuts temperatures as low as this were not encountered, but successful fumigations were done at commodity temperatures as low as 52° with outside temperatures of 45° and car temperatures as low as 54° F. From the results of other investigations on low temperatures (as yet unpublished) it is believed that successful results can be obtained at commodity temperatures as low as 20° F. (and possibly lower) as long as the problems of volatilizing the gas can be overcome.

With full sunshine beating on the walls and roofs of the cars, inside temperatures as high as 107° F. have been observed.

Wind velocities as high as 20 miles per hour were recorded during the fumigations. It is concluded that, as a result of extended observations on this point, wind velocity has no effect on the success of freight car fumigation, provided good cars and adequate sealing are employed.

Effect of Fumigation on the Commodities

No complaints of alteration in taste or processing qualities were received as the result of the fumigation with methyl bromide of imported peanuts and cotton seed meal, and exported chicory, wheat, and chick peas. In the case of the peanuts, manufacturers of peanut butter were contacted in several cities and the statement elicited that the fumigant had had no appreciable effect on taste. Tests in the Fumigation Laboratory at Montreal, P.Q., made on the chicory also failed to show any effect on the flavour of ground chicory.

Samples of peanuts removed from the cars after fumigation were submitted to the Dow Chemical Corporation, Midland, Michigan, for analysis in their laboratories. The results of this analysis are given in Table 3. The first sample of American peanuts was obtained during the

TABLE 3.—RESIDUES IN PEANUTS FUMIGATED WITH METHYL BROMIDE IN FREIGHT CARS

Sample	Total bromide %	Remarks
American peanuts Car CN 476533, 3,712 cu. ft. containing 65 bales of broom corn. Dose—16 pounds of methyl bromide for 20 hrs. Temperature—25° F. in bag peanuts.	0.0028	
Control, non-fumigated	0.0001	
Nigerian peanuts 100 lbs. Proxate, May 20, 24 hrs., 3,000 cu. ft. commodity at 64° F., NYC 130440	0.0010	
10 lbs. methyl bromide in pans, 24 hrs., May 20, commodity at 65° F., C & O 12533, 3,000 cu. ft.	0.0009	
First fumigation, Erie 70927, 2,926 cu. ft., 10 lbs., CH ₃ Br with applicator, May 19, 24 hrs. at 60° F. Second fumigation, CP 221264, 3,715 cu. ft., 100 lbs., Proxate, 24 hrs., May 24 at 64° F.	0.0015	Repeat due to failure in application.
Control, non-fumigated ex WAB 82361	0.0004	

fumigation of broom corn at low temperatures. The figures obtained are somewhat lower than those quoted by Dudley and Neal (2) for whole nut, unroasted peanuts. These authors exposed peanuts and other products to a dosage of two pounds of methyl bromide per thousand cubic feet for 24 hours at 68-77° F. and obtained the following residues in the peanuts:

Mg. Br./100 gm. sample

Sample	Before fumigation (control)	Immediately after fumigation	24 hours after fumigation	48 hours after fumigation
Peanuts, whole nut, unroasted	None	5.04	5.00	5.00
	0	Expressed as percentage total bromide		
		.00504	.0050	.0050

None of these residues, however, can be interpreted as of any significance from the point of view of human consumption, according to observations made by Dudley and Neal (2), Flinn (3) and Clark *et al.* (1).

SUMMARY

1. A description is given of a successful campaign to prevent the spread of stored product insects found in imported plant products. The infestations were eliminated chiefly by fumigation with methyl bromide in steel freight cars at the port of importation or at destination.

2. An account is also given of freight car treatments of exported food-stuffs prior to loading on board the steamship.

3. With the selection of suitable types of steel freight cars satisfactory control of several species of stored product insects was obtained in shelled peanuts, wheat in bags, chick peas, and cotton seed meal. In most cases complete mortality of all the insects present was obtained.

4. The methyl bromide fumigation appeared to have no adverse effects on the products treated and residues analysed in fumigated peanuts were of no toxicological significance.

5. For steel freight cars of airtight construction a dose of 1.5 lb. of methyl bromide per thousand cubic feet is recommended for exposure periods of 16 to 24 hours at temperatures of 60° F. and above. A graduated increase in dose for lower temperatures is provisionally suggested.

ACKNOWLEDGMENTS

The authors wish to acknowledge the helpful co-operation and support given by Mr. W. N. Keenan, Chief of the Division of Plant Protection, Ottawa, under whose direction this work was carried on. Thanks are due to Professor E. R. Bellemare, Secretary, Canadian Pest Control Operators' Association, who gave freely of his time to assist in organizing the work and in making contact with the members of his association, and to Mr. M. J. Murphy, Traffic Manager, Harrisons & Crosfield (Canada) Limited, representing the Bulk Purchasing Division of the Commodity Prices Stabilization Corporation, whose valuable time was utilized on numerous occasions in planning the work.

The data on which this paper is based were gathered by the district inspectors and their staffs in the offices of the Division of Plant Protection in the districts throughout the country where freight car fumigations were carried on. The district inspectors concerned were: Messrs. R. G. Webber, Halifax, N.S.; A. Finnamore, Saint John, N.B.; L. R. Gagnon, Quebec, P.Q.; W. St. G. Ryan, Montreal, P.Q.; A. Fowler, Toronto, Ont.; F. J. Hudson, London, Ont.; and H. F. Olds, Vancouver, B.C. In addition valuable suggestions and observations were made by Messrs. A. E. McCollom and W. S. Hoar of the Saint John office.

The representatives of the fumigating companies doing this work under our supervision were also very helpful in arranging their treatment schedules to enable us on many occasions to gain special data and take photographs. In this connection we would like to mention Messrs. G. Worth of the Pestroy Co. Ltd., Montreal, P.Q.; E. J. Gentle of the Pest Control Service, Hamilton, Ont.; J. C. Otis of the Mysto, Inc., Montreal, P.Q.; W. R. Beatty of the Johnston National Storage Ltd., Vancouver, B.C.; and H. W. Johnson of Canadian Service and Sales Co., Verdun, P.Q.

Blueprints showing the construction of various types of cars were loaned by officers of the equipment departments of the two principal Canadian Railway companies, who also supplied important data and lists of car series. These officers were, for the Canadian National Railways, Mr. E. R. Battley, Chief of Motive Power and Car Equipment, and Mr. G. E. McCoy, Assistant Chief of Car Equipment, and for the Canadian Pacific Railway Company, Mr. H. B. Bowen, Chief of Motive Power and Rolling Stock, and Mr. H. B. Winship, Mechanical Engineer.

We are indebted to Mr. H. G. Carmody of the Toronto Office of this Division for preparing the illustrations for Figures 2 and 3.

REFERENCES

1. CLARK, B. B., W. L. ADAMS and R. MORRISSEY. The effect of repeated daily administration of sodium bromide on the blood and electro-cardiogram of dogs. *Sci. Proc. Am. Soc. Pharmacol. and Exper. Ther.* (New Orleans meeting), p. 8. 1940.
2. DUDLEY, H. C. and PAUL A. NEAL. Methyl bromide as a fumigant for foods. *Food Research* 7 : 421-429. 1942.
3. FLINN, F. B. The appearance of blood bromide after oral ingestion. *Journ. Lab. and Clin. Med.* 26 : 1325-1329. 1941.
4. McLAINE, L. S. The war activities of the Federal Divisions of Entomology and Plant Protection since 1939. 73rd Annual Report of the Entomological Society of Ontario, 7-16. 1943.
5. MONRO, H. A. U. and R. DELISLE. Further applications of methyl bromide as a fumigant. *Sci. Agr.* 22 : 170-177. 1941.

THE RETENTION OF NUTRIENTS IN CHEESE MAKING

I. • THE RETENTION OF CALCIUM, PHOSPHORUS AND RIBOFLAVIN IN CHEDDAR CHEESE MADE FROM RAW MILK¹

O. R. IRVINE², L. R. BRYANT³, AND W. H. SPOULE⁴

Ontario Agricultural College, Guelph, Ontario

and

S. H. JACKSON⁵, A. CROOK⁶, AND W. M. JOHNSTONE⁷

Hospital for Sick Children, Toronto, Ontario

[Received for publication June 25, 1945]

Cheese of the cheddar variety was one of the first dairy products manufactured on a commercial scale in Canada. Since its inception the cheese industry has served as the chief means whereby Canadian dairymen have been able to conserve and market much of the milk produced during the seasons of heavy production. Cheese manufacture has continued to maintain this position of leadership in spite of the fact that more modern methods of preserving the nutrients of milk have since been perfected.

It is recognized that in the cheese making process, a portion of the milk nutrients is not retained. The nutrients which are not retained consist chiefly of lactose and albumin as well as relatively large proportions of the minerals and water-soluble vitamins. Whey, the by-product of cheese making, is utilized largely in the feeding of farm animals and this fact, in conjunction with the relatively low cost of manufacturing, tends to compensate for these losses.

While the proportions of these constituents which are lost in the whey are comparatively great, the retention efficiencies for fat, casein and vitamin A are relatively high, with the result that cheddar cheese is generally listed as an excellent source of these nutrients. However, no data appear to exist for calcium and phosphorus retention in Canadian cheese. Furthermore, retention of the B-complex vitamins has not been a subject of extensive study.

It was for these reasons that this project was undertaken. In it, a study has been made of the proportions of the calcium, phosphorus and riboflavin which are lost in the whey and retained in the cheese when unpasteurized milk is manufactured into Canadian cheddar cheese. The stability of the riboflavin throughout a ripening period of twelve months has also been determined. In addition, data are presented on milk and cheese obtained from four different soil areas of Southern Ontario. A number of samples of cheese displaying flavour defects are also reported on.

The study has been carried out as a co-operative project and joint contribution between the Ontario Agricultural College, Guelph, and the Department of Pediatrics, Hospital for Sick Children, University of Toronto.

¹ Joint contribution from the Departments of Dairying and Chemistry, O.A.C., and the Department of Paediatrics, Hospital for Sick Children, Toronto. Determinations for fat and total solids were made in the Dairy Chemistry laboratory, O.A.C., while those for calcium, phosphorus and riboflavin were made at the Hospital for Sick Children.

², ⁴ Lecturer and Professor, respectively, Department of Dairying.

³ Associate Professor and Dairy Chemist, Department of Chemistry.

⁵ Research Assistant in Chemistry.

⁶, ⁷ Technical Assistants, Department of Paediatrics' Research Laboratories.

HISTORICAL

McCammon, Caulfield and Kramer (9) have reported on the calcium and phosphorus contents of American cheddar cheese made under controlled conditions. Their values indicated that 80% of the calcium and 38% of the phosphorus originally present in the milk, were retained in the cheese. Approximately 85% of the phosphorus was accounted for by the protein. The method of manufacture influenced the retention of calcium in that increasing the acidity at renneting resulted in increased losses of calcium in the whey.

Mattick (11), reporting on English cheddar, found that 65-68% of the calcium and 51-60% of the phosphorus were retained. Practically the whole of the mineral loss took place at the time the whey was run.

McDowall and Dolby (10) state that for New Zealand cheese, in normal operations 60% of the calcium and 57% of the phosphorus are retained. The mineral content of the whey increased steadily as the process of manufacture advanced except for a temporary fall after salting. Zahrndt, Lane and Hammer (18) studied the calcium, phosphorus and calcium/phosphorus ratios of a number of cheddar cheese samples from Iowa, Wisconsin and New York and concluded that differences in these values are only such as might be attributed to sampling variations.

Studies on the vitamin content of cheese aside from some of the fat soluble vitamins, have been quite limited. In the case of the cheddar variety Houston and Kon (4) give a value of 310 μ g. of riboflavin per 100 grams in a preliminary report while Munsell (12) found that American cheddar contained 545-600 μ g. per 100 grams. Day and Darby (3) were among the earlier workers to recommend American cheddar as a source of this vitamin. Sullivan, Bloom and Jarmol (16) found that variations in the riboflavin content of Limburger cheese during ripening, were less marked than for the other vitamins of the B group.

EXPERIMENTAL

In order to secure as reliable a picture as possible of the retention and losses of these nutrients in the cheese making process, the experimental program was extended over a full year, while an additional 12-month period was required to complete the ripening of the last batch of cheese. In addition a small number of samples was secured at different points in Ontario with a view to determining whether or not the regular experimental results were of the same order as those prevailing at commercial plants.

The procedure in the main experiment consisted of manufacturing approximately 1200-1800 pounds of milk into cheddar cheese using the recognized commercial technique as commonly practiced for this variety. A vat was made up each month during the period May, 1942 to April, 1943. The resulting cheese from each batch were divided into two lots, one of which was ripened at 40° F. while the other was ripened at 58° F. Samples were taken at intervals until the cheese were one year old.

The milk used in the study was secured from the College herd which consists of Holstein, Jersey and Ayrshire breeds. On one or two occasions it was necessary to supplement this supply with a small amount from an

outside source. All the milk was regularly of good quality. While experimental manufacturing operations extended over a year, every effort was made to maintain the greatest possible uniformity in manufacturing conditions.

Two samples of the milk plus starter were secured in 8-oz. amber bottles after thorough mixing. Similar samples of the "first" whey and "press" whey were also secured. The term "first" whey, as used in this study, includes all the whey which drained from the curd during running and stirring as well as that which continued to drain from the curds until they were cut and turned the second time after piling. "Press" whey includes all the brine which drained from the curd after salting as well as that which was expressed from the cheese in the press up to the time of dressing the cheese. The weight of the first whey was estimated by measuring it in a calibrated cylindrical tank while the weight of the press whey was determined by weighing.

The curds were pressed into Stilton-shaped cheese of approximately 10 pound each. On the morning following manufacture, three of these were cut in halves, the resulting 5-lb. pieces being used for scoring. The procedure followed for sampling the cheese for analysis in this as well as for subsequent series, consisted of removing the outer rind plus an additional slice of cheese approximately 2 cm. thick from the end of a 10-pound cheese. A second slice was then taken of approximately the same thickness. This disc was then cut into wedges, two of which were wrapped in moisture-proof cellophane and forwarded to each of the laboratories for analysis.

As soon after sampling as possible, the cut surfaces of the cheeses were re-paraffined, thus allowing the same cheese to serve as a source of material for subsequent sampling. The details of sampling and analysis on the milk, whey, and cheese are shown in Table 1.

TABLE 1.—SCHEDULE FOR SAMPLING AND ANALYSIS OF MILK, WHEY AND CHEESE

	Milk	First whey	Press whey
Fat	X	X	X
T.S.	X	X	X
Ca	X	X	X
P	X	X	X
Ribo	X	X	X

Cheese (ripened at 40° F. and 58° F.)

[illegible]

METHODS OF ANALYSIS

Preparation of Sample for Total Solids and Fat Determinations

Approximately 3 mm. was removed from the outside edge of the sample (sufficient to remove all the cheesecloth and a small portion of the rind). The sample was then passed through a food grinder, of the ordinary kitchen type, three times, and transferred to an air-tight, screw cap bottle. This procedure was completed as quickly as possible to insure a minimum loss of moisture.

Total Solids Determination

An aluminium dish 55 mm. in diameter and 15 mm. in depth, provided with a slip-in inverted cover fitting tightly on the inside was used. Two to three grams of the sample was weighed into the previously heated and weighed dish, covered tightly and reweighed. The lid and dish were then placed separately in a cool oven, heated to 100° C. and held at that temperature for 24 hours. The cover was then replaced, and the dish cooled and weighed again. Each sample was done in duplicate.

Fat Determination

The standard Mojonnier procedure for fat determination on cheese was used throughout, and each sample was treated in duplicate. Approximately one gram of the ground cheese was introduced into a previously weighed Mojonnier fat flask, stoppered tightly and reweighed. Eight ml. of hot water was added and the flask thoroughly shaken. Three ml. ammonia solution was then added and the flask thoroughly shaken again. At this point it was necessary to make certain that all cheese was thoroughly dispersed. Then 10 ml. alcohol, 25 ml. ethyl ether and 25 ml. petroleum ether were added, shaking one-half minute after the addition of the alcohol, and 20 seconds after the addition of the two ethers. The flasks were centrifuged for 30 turns in one-half minute. The ether layer was then poured off into a heated and weighed fat dish and evaporated to dryness. The second extraction was then carried out in the standard manner. This method for the determination of fat gives somewhat low results as compared with Official Methods (2).

Calcium

The samples were ashed at 550° C. under sodium carbonate. The ash was taken up in nitric acid, diluted to a definite volume and filtered. The calcium was determined in an aliquot of the filtrate by precipitation as calcium oxalate and titration with potassium permanganate by the method of Kramer and Tisdall (7).

Phosphorus

An aliquot of the ash solution used for the calcium determination was evaporated with a small amount of concentrated sulphuric acid and heated until fuming to expel the nitric acid and hydrolyze any pyro-phosphates present. After dilution, the phosphorus was determined colorimetrically, using the Evelyn photo-electric-colorimeter.

Riboflavin

The cheese sample was ground and a suitable aliquot was weighed out. This was mixed with 50 ml. of 0.1 N H Cl and autoclaved at 15 lb. steam pressure for $\frac{1}{2}$ hour. After cooling, 1 ml. of 2.5 M sodium acetate was added and the pH adjusted to 6.8. It was filtered and the precipitate re-extracted with 25 ml. of N/10 H Cl, cooled, the pH adjusted to 4.5 and filtered. The precipitate and filter were then washed with water several times and the combined extracts and washings adjusted to pH 6.8 and diluted to 200 ml. volume.

The riboflavin in the extracts was determined by the Snell and Strong microbiological assay method, used without modification (15).

Preparation of the extract in this way was found to eliminate interfering fatty materials by entrapping them on the voluminous precipitate that formed at pH 4.5. Preliminary removal of the fats by ether extraction of the cheese did not affect the results.

RESULTS

As an indication of the methods followed in handling the curds in this study, Table 2 presents the pertinent values which were obtained in the cheesemaking process.

TABLE 2.—DETAILS OF THE CHEESE-MAKING PROCESS

Date of mfg. and lot number		Starter	Milk ripening period	Setting acidity	Set to run	Running acidity	Run. to salt
		%	— min.	%	— min.	%	— min.
26/5/42	1	1.0	50	0.195	155	0.18	230
29/6	2	1.0	96	0.185	134	0.185	220
27/7	3	1.0	90	0.18	160	0.18	225
26/8	4	1.0	72	0.185	188	0.185	180
30/9	5	1.25	75	0.19	155	0.18	255
20/10	6	1.50	65	0.19	120	0.19	190
19/11	7	1.25	72	0.185	178	0.20	190
15/12	8	1.0	71	0.19	178	0.18	240
18/1/43	9	1.4	94	0.175	201	0.175	190
24/2	10	1.5	85	0.18	170	0.185	185
16/3	11	1.5	80	0.175	160	0.175	225
21/4	12	1.0	115	0.185	160	0.175	205

Rennet extract was used at a rate of 3 fl. oz. per 1000 lb. milk.
Salt was added at a rate of 2.25 lb. per 1000 lb. milk.

It will be observed that variations occurred in the amount of starter employed, in the setting and dipping acidities as well as in the lengths of times the curds were in the whey. These variations are to be expected over a full year and were necessary in order to secure good quality cheese.

Retention of Calcium in Cheese

In order to increase the clarity of this presentation, many of the data have been tabulated and are presented in an appendix. (Tables 10, 11 and 12). The efficiency of the cheesemaking process as a means of retaining these nutrients, has been ascertained by calculating the percentage of

the nutrient originally present in the milk which is accounted for in the cheese. In the case of calcium these values are presented in Table 3.

TABLE 3.—LOSSES AND RETENTIONS OF CALCIUM IN CHEDDAR CHEESE-MAKING

Lot No.	First whey	Press whey	Cheese	Total
	%	%	%	%
1	36.5	0.68	60.5	97.7
2	43.5	0.9	57.5	101.9
3	42.5	1.0	56.3	99.8
4	—	1.0	65.0	—
5	37.4	1.35	63.0	101.75
6	35.9	1.4	60.3	97.6
7	45.1	1.0	57.3	103.4
8	36.8	1.3	65.0	103.1
9	33.7	1.0	65.3	100.0
10	34.5	0.8	59.0	94.3
11	37.8	0.8	63.0	101.6
12	36.6	0.8	63.0	100.4
Means	38.1	1.0	61.3	100.4

The proportion of calcium retained in the cheese is quite consistent in these twelve trials. A comparison of these values with the cheesemaking record (Table 2) fails to indicate any close correlation between calcium losses and high acidities or "fast working" curds. It may be assumed therefore, that the minor variations which commonly occur in cheddar cheesemaking technique from day to day or from factory to factory, are unlikely to alter the efficiency with which this element is retained in the cheese. No evidence of seasonal variation in retentions of calcium can be noted.

Retention of Phosphorus

Values on phosphorus retention have been calculated in a manner similar to those for calcium and are presented in Table 4.

TABLE 4.—LOSSES AND RETENTIONS OF PHOSPHORUS IN CHEDDAR CHEESE-MAKING

Lot No.	First whey	Press whey	Cheese	Total
	%	%	%	%
1	53.6	0.62	52.5	106.7
2	48.1	0.7	51.0	99.8
3	47.5	0.7	49.0	97.2
4	43.5	0.7	54.8	99.0
5	45.2	0.9	55.0	101.1
6	44.8	1.0	53.3	99.1
7	48.5	0.5	50.0	99.0
8	46.0	1.0	55.6	102.6
9	40.0	0.6	57.0	97.6
10	44.0	0.7	50.0	94.7
11	44.9	0.6	51.7	97.2
12	46.8	0.6	57.8	105.2
Means	46.1	0.72	53.1	99.9

* These values indicate that the proportion of phosphorus lost is greater than that for calcium. Coefficients of variation have not been calculated but they appear to be about equal for both sets of values. If a comparison of the above values is made with those of Table 3, it will be noted that in most instances, where losses of calcium are above the average, those of phosphorus are also. The same factors may, therefore, be assumed to affect the retention of both these minerals.

Retention of Riboflavin

Milk is an abundant source of riboflavin but the extent to which this vitamin is retained in other dairy products has not been fully established. The higher the rate of retention the more valuable will be the product. In Table 5 will be found the proportions of this vitamin accounted for either in the first whey, press whey or in cheese one day old. Once again these values are presented as percentages of the amount originally present in the milk.

TABLE 5.—LOSSES AND RETENTIONS OF RIBOFLAVIN IN CHEDDAR CHEESE-MAKING

Lot No.	First whey	Press whey	Cheese (1 day old)	Total
	%	%	%	%
1	65.0	0.25	24.0	89.2
2	59.5	0.3	18.0	77.8
3	57.2	0.45	20.0	77.6
4	59.0	0.4	20.6	80.0
5	68.0	0.46	25.0	93.5
6	51.5	0.6	25.5	77.6
7	66.0	0.3	20.5	86.8
8	70.0	0.5	25.2	95.7
9	76.0	0.5	32.0	108.5
10	76.0	0.45	23.6	100.0
11	80.0	0.5	22.2	102.7
12	57.0	0.5	23.0	80.5
Means	65.4	0.43	23.3	89.13

In view of the fact that riboflavin is a water-soluble substance, an average rate of retention of 23.3% is better than might be anticipated. The range of values here is much greater than is the case for either of the minerals and there is no evidence to indicate that losses of minerals and vitamins might be correlated. Low retention rates may be due to higher than average losses in the whey or to destruction of this nutrient during manufacture. The possibility of finding ways of retaining a higher proportion of this substance in the cheese is therefore, something of a challenge. Some of the methods by which this might be achieved are dealt with in the discussion.

THE STABILITY OF RIBOFLAVIN DURING RIPENING

The study of changes in riboflavin content during ripening is complicated by the fact that the moisture content of cheese usually varies slightly from vat to vat and also that "shrinkage," due to evaporation of moisture from the cheese, goes on throughout the ripening period. In these experiments shrinkage was accelerated as a result of the fact that the cheese were small. Table 11 in the Appendix shows the values for fat and

total solids content for cheese ripened at the two temperatures. Figure 1, which is a graph of the mean values for total solids at the two ripening temperatures should be of special interest to everyone concerned with

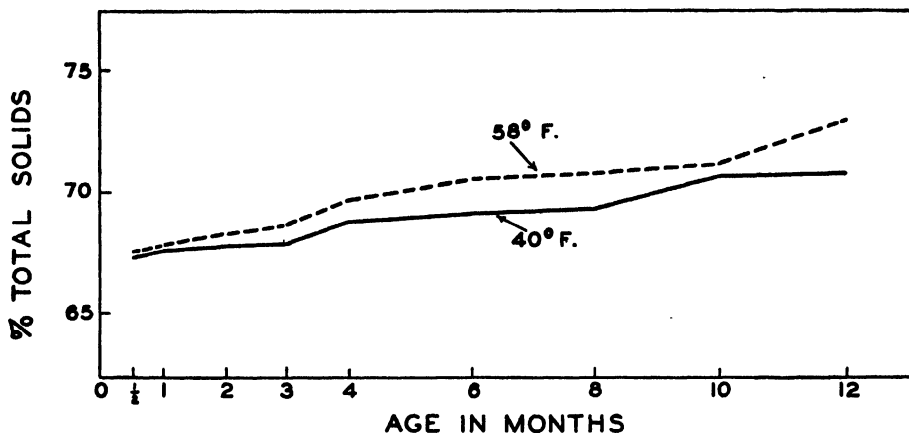


FIGURE 1. Increase in total solids content of cheese as a result of evaporation during ripening.

cheese manufacture since it indicates that shrinkage is a problem throughout the whole of the ripening period. In the case of these cheese the rate of moisture loss is accentuated by the fact that the surface area was large in proportion to the weight of the cheese, and also by the fact that the relative humidity of the storages was not always maintained at a very high level.

In order to correct for this shrinkage error which tends to distort the riboflavin results, these values have been calculated to a 35% moisture content basis. The minimum, maximum and mean values throughout the ripening period at the two temperatures used, are presented in Table 6 and in graph form in Figure 2.

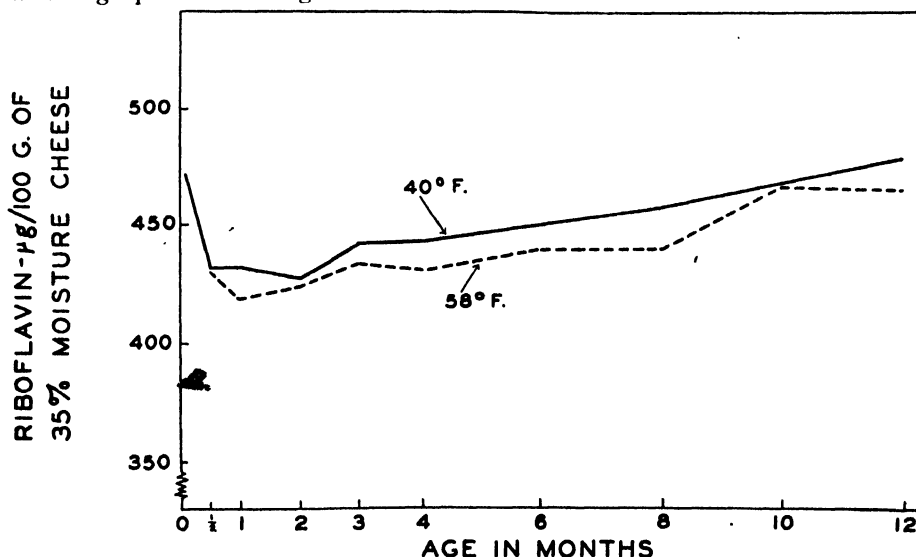


FIGURE 2. Variations in riboflavin content of cheese during ripening. Average of 12 lots.

TABLE 6.—STABILITY OF RIBOFLAVIN DURING RIPENING*

Age	Ripening temperature—40° F.									
	1	14 da.	1	2	3	4	6	8	10	12 mo.
Min.	390	374	367	364	380	413	408	420	444	429
Max.	585	483	468	470	485	492	487	496	530	540
Mean	468	434	434	428	444	444	451	457	467	477
	Ripening temperature—58° F.									
	1	14 da.	1	2	3	4	6	8	10	12 mo.
Min.	390	393	332	365	391	391	428	403	437	432
Max.	585	474	463	461	479	468	470	459	513	515
Mean	468	434	420	424	435	431	442	440	464	465

* The results presented are the minimum, maximum and mean values on 12 lots in micrograms per 100 g. of 35% moisture cheese.

From an examination of the data in Table 6, it is quite evident that the riboflavin content of cheese is not adversely affected, even after extended periods of ripening at relatively high temperatures. The range of values is narrow and it may therefore be concluded that any sample of cheese which has been manufactured under similar conditions could be expected to be an equally good source of this vitamin.

It will be noted that from the beginning of ripening until the second month, a diminution in riboflavin values takes place, after which a gradual increase occurs until at the end of the 12-month period values slightly in excess of the original ones prevail. This fluctuation is more pronounced at the higher ripening temperature. The factors which produce these variations are not known but some of the probable causes are discussed below.

THE EFFECT OF DIFFERENT SOIL TYPES ON CALCIUM, PHOSPHORUS AND RIBOFLAVIN CONTENT OF MILK, AND THE CHEESE MANUFACTURED FROM IT

In order to ascertain whether the results of the main experiment were in accord with results which might be secured at commercial factories, it was decided to obtain samples of milk and cheese at factories in different parts of the province, and carry out similar analyses to those reported above. This also afforded an opportunity to select areas which were representative of different soil types and thus determine whether soil might be a factor in influencing the mineral relationships of the milk. The localities listed below were suggested by Prof. F. F. Morwick of the O.A.C. Soils Division as being good examples of the soil types desired. Arrangements were therefore made to visit these plants and obtain samples. Visits were made during June and again during September of 1942.

At each factory a vat of milk was selected and samples of the milk plus starter were taken just before rennetting. Whey samples were secured at the running stage. When the curds were ready for pressing, two 10-pound hoops were filled from the vat and pressed into cheese. The milk

and whey samples were chilled and dispatched to the laboratories while samples of cheese were forwarded on the following day. The two cheeses were then expressed to Guelph where they were held for six months at 40° F. Samples of these were assayed for riboflavin at one and 14 days and at 6 months. The results of the study are presented in Table 7.

TABLE 7.—EFFECT OF LOCALITY ON CALCIUM, PHOSPHORUS AND RIBOFLAVIN CONTENT OF MILK AND THE CHEESE MANUFACTURED FROM IT

Factory	County	Soil characteristics	Date	Fat	Milk			
					T.S.	Ca	P	Ribo.
				%	%	(mg. %)		(µg. per 100 g.)
1223 Homestead	Oxford	P deficient; fair lime	June	3.09	11.38	—	—	205
			Sept.	3.08	11.28	111	70	196
239 Selwyn	Peterborough	High lime; fair total P but low available P	June	—	—	125	95	199
			Sept.	3.45	12.01	123	82	192
943 Marvelville	Carleton	Suitable Ca/P balance; good fertility	June	3.21	11.53	118	86	204
			Sept.	3.11	11.53	114	76	212
632 Milbrook	Russell	Acid soil area	June	3.51	12.32	117	84	187
			Sept.	3.52	12.07	114	70	207
Factory	Date	Cheese						
		Ca	P	Riboflavin (µg. per 100 g. of 35% moisture cheese)				
		(mg. %)		1 da.	14 da.	6 mo.		
1223	June Sept.	—	—	—	439	527		
		676	440	430	482	484		
239	June Sept.	820	508	408	392	—		
		616	432	446	452	462		
943	June Sept.	640	424	418	393	520		
		624	414	466	466	495		
632	June Sept.	724	424	473	395	452		
		632	404	470	436	482		

These results are of much the same order as those found in the main experiment. Because of their confirmatory character they strengthen the evidence that minor variations in cheese making methods or in milk supplies are not likely to affect markedly the nutritive value of cheese in respect to minerals or riboflavin.

CALCIUM, PHOSPHORUS AND RIBOFLAVIN IN CHEESE POSSESSING DEFECTIVE FLAVOURS

It was thought possible that cheese of poor flavour quality might display abnormal values for these nutrients either because of undesirable fermentations in the process or for some other cause. Through the kindness of the dairy produce graders of the Dominion Department of Agricul-

ture, a number of second and third grade samples were secured. An equal number of first grade samples were also sent along to serve as controls. The results are presented in Table 8. Except for the one sample of "not clean" cheese, the results are averages of several samples.

TABLE 8.—CALCIUM, PHOSPHORUS AND RIBOFLAVIN IN FLAVOUR DEFECTIVE CHEESE COMPARED WITH THOSE OF FIRST GRADE FLAVOUR

Flavour	No. of samples	Ca	P	Riboflavin μg./100 g.
		mg. %	mg. %	
Off	3	527	467	448
Rancid	4	555	414	464
Fruity	4	608	428	451
Not clean	1	476	412	472
First grade	12	561	420	462

In the case of the mineral results, the individual values from which these averages were calculated displayed a greater variation than did the results in the controlled experiment. This was true of the results from both defective and first grade samples. It will be noted from the averages, however, that, except for the one "not clean" sample, these values do not vary markedly from the first grade controls. With regard to riboflavin, it is apparent that the factors causing defective flavour do not affect adversely the retention of this vitamin.

DISCUSSION

The results of the cheese analyses for mineral content reported in this paper, are far from being in agreement with those of McCammon, Caulfield and Kramer (9), who reported retentions of 80% for calcium and 38% for phosphorus. In the present study the fact that it has been possible to account for almost all the minerals, either in the whey or cheese, increases our confidence in the methods of analysis which were used. The retention of phosphorus would appear to be particularly low in the above-mentioned study in view of the fact that much of the phosphorus of milk is present as a constituent of casein. On the other hand the values here reported are in close agreement with those of Mattick (11).

Confirmatory evidence is furnished in this study that the riboflavin content of milk is not affected by season or by shifts from pasture to stable feeding or *vice versa*. This is now the accepted view (5, 6), although the claim has been made by others (1, 17,) that the riboflavin content of milk can be increased from 50 to 75% by increasing this factor in the ration.

Houston and Kon (4) have commented on the fact that retentions of riboflavin in English cheeses are about five times greater than can be accounted for on the basis of this vitamin's water solubility. This may result from the fact that a part of the riboflavin in milk is known to be present as riboflavin-protein complexes. Kuhn and Kaltschmitt (8) note that 10% of this vitamin in milk is in an undialysable form. Sharp (13) has stated that this flavoprotein (probably Schardinger enzyme or xanthine oxidase) is closely adsorbed on the fat globule. He (with Hand) has also stated (14) that the proportion of riboflavin adsorbed can be maintained at a maximum by methods which involved temperature changes.

One feature of the riboflavin picture which should receive further study is the seasonal variation in the unaccountable loss of riboflavin during manufacture. Table 5 above contains the percentages of riboflavin either lost in the wheys or recovered in the cheese in the twelve trials. The totals of these values have been arranged in two groups in Table 9.

TABLE 9.—LOSSES OF RIBOFLAVIN DURING MANUFACTURE AT DIFFERENT SEASONS OF THE YEAR

Total recovery of riboflavin in wheys and cheese as percentage of original in milk			
Winter months		Summer months	
	%		%
Nov.	86.8	May	89.2
Dec.	95.7	June	77.8
Jan.	108.5	July	77.6
Feb.	100.0	Aug.	80.0
Mar.	102.7	Sept.	93.5
Apr.	80.5	Oct.	77.6
Mean	95.7		82.6
Loss not accounted for	4.3		17.4

It is suggested that the loss may be due to the destruction of this vitamin by light, the much higher loss during the summer months being the result of greater light intensity during that period. This explanation seems plausible since the laboratory in which the cheese were made is a well-lighted one and is not shaded by trees during the summer. It is planned to study the possible effect of light in a later project.

SUMMARY

A study has been made of the losses and retentions of calcium, phosphorus, and riboflavin in Canadian cheddar cheese made from raw milk. The effect of ripening the cheese for 12 months on the stability of riboflavin was also studied.

Of the original calcium present in the milk, about 61% was retained in the cheese. Of the original phosphorus, about 53% was accounted for in the cheese. These values were subject to small variations but did not vary with season, nor could they be correlated with minor changes in cheesemaking methods. The losses were almost entirely accounted for in the whey removed during running and stirring.

About 23% of the riboflavin originally present in the milk was retained in the cheese. The variations in this case were of somewhat greater proportions. Riboflavin appeared to be stable throughout a ripening period of 12 months both at temperatures of 40° and 58° F. There was an apparent diminution during the first two months but this was followed by an equal increase during the final months of ripening.

A small number of samples of milk and cheese were secured from factories in the province which represented varying soil types. Soil does not appear to be a significant factor affecting mineral retention in cheese. Riboflavin values were similar to those in the main experiment.

The calcium, phosphorus and riboflavin contents of cheese of defective flavour appear to be essentially the same as those of first grade cheese.

ACKNOWLEDGMENTS

We wish to extend our thanks to the Ontario Cheese Producers' Association of Belleville, Ontario who contributed a generous grant for this project. We are also indebted to the cheese factory operators from whom samples were obtained and to the dairy produce graders of the Dominion Department of Agriculture who forwarded samples of cheese.

REFERENCES

1. ASSOCIATES OF ROGERS. *Fundamentals of Dairy Science*. Reinhold Publishing Corp. New York, U.S.A., p. 509. 1935.
2. BABEL, F. J., and F. E. NELSON. Comparison of methods for determination of fat content of cheese. *Nat. Butter and Cheese Jour.* 36 : 9; 18. Sept. 1944.
3. DAY, P. L., and W. J. DARBY. The cataract-preventive vitamin (flavin) in cheese. *Food Res.* 1 : 349. 1936.
4. HOUSTON, J., and S. K. KON. Reported by H. D. Kay. Cheese: some recent chemical and physico-chemical findings. *Chem. & Ind.* 60 : 411. 1940.
5. JOHNSTON, PAUL, L. A. MAYNARD, and J. K. LOOSLI. The riboflavin content of milk as influenced by diet. *Jour. Dairy Sci.* 24 : 1; 57. 1941.
6. KRAMER, M. M., R. M. DICKMAN, M. L. HILDRETH, B. L. KUNERTH, and W. H. RIDDELL. The riboflavin value of milk. *Jour. Dairy Sci.* 22 : 9; 753. 1939.
7. KRAMER, BENJAMIN, and FREDERICK F. TISDALL. A simple technique for the determination of calcium and magnesium in small amounts of serum. *Jour. Biol. Chem.* 47 : 3; 475. 1921.
8. KAHN, R., and H. KALTSCHMITT. Ueber den Zustand des Vitamins B₂ in der Kuhmilch. *Ber. d. deutsch Chem. Gesellsch.* 68 : 386. 1935. (Original not seen).
9. McCAMMON, R. B., W. J. CAULFIELD, and M. M. KRAMER. Calcium and phosphorus of cheese made under controlled conditions. *Jour. Dairy Sci.* 16 : 3; 253. 1933.
10. McDOWALL, F. H., and R. M. DOLBY. Studies on the chemistry of cheddar cheese-making. I. The mineral content of cheese and whey. *Jour. Dairy Res.* 6 : 218. 1935.
11. MATTICK, E. C. V. The calcium and phosphorus content of some types of British cheese at various stages during manufacture and ripening. *Jour. Dairy Res.* 9 : 233. 1938.
12. MUNSELL, HAZEL E. Riboflavin content of some common foods. *Food Res.* 7 : 2; 85. 1942.
13. SHARP, PAUL F. The milk fat globule. *Jour. Dairy Sci.* 23 : 8; 771. 1940.
14. SHARP, PAUL F., and DAVID B. HAND. Riboflavin, vitamin C. and flavour of dairy products. *Proc. 1st Inst. Food Tech.* p. 139. 1940.
15. SNELL, E. F., and F. M. STRONG. A microbiological assay for riboflavin. *Ind. Eng. Chem., Analyt. Ed.* 11 : 6; 346. 1939.
16. SULLIVAN, R. A., E. BLOOM, and J. JARMOL. The value of dairy products in nutrition. III. The riboflavin, pantothenic acid, nicotinic acid, and biotin content of several varieties of cheese. *Jour. Nutr.* 25 : 5; 463. 1943.
17. YEARBOOK OF AGRICULTURE, U.S.D.A., 1939. "Food and Life." U.S. Government Printing office, Washington, D.C. p. 676. 1939.
18. ZAHNEDT, H. J., C. B. LANE, and B. W. HAMMER. Bacteriology of cheese. VII. Calcium and phosphorus contents of various cheese, including relationship to bacterial action in the manufacturing procedures. *Iowa Agr. Expt. Sta. Res. Bul.* 325. 1944.

TABLE 10.—CA, P, AND RIBOFLAVIN IN MILK, FIRST WHEY,
PRESS WHEY AND ONE-DAY OLD CHEESE

Lot G No.	Milk					First whey						
	Fat	T.S.	Ca	P	Ribo.	Yield	Fat	T.S.	Ca	P	Ribo.	
	*	*	*	**	***	*	*	*	**	**	***	
1	4.26	13.08	134.0	90	194	88.0	0.39	7.05	55.3	55	144	
2	3.73	12.40	123.5	85	207	92.2	0.32	6.92	58.0	44	132	
3	3.78	12.51	125.5	88	194	87.9	0.36	6.93	60.8	47.5	126	
4	4.66	12.54	120.0	90	207	87.2	0.37	6.97	69.0	45	180	
5	3.95	12.83	118.5	85	202	85.8	0.35	7.06	50.8	44	158	
6	4.00	12.90	128.5	87	193	87.4	0.39	6.77	52.0	43.8	112	
7	3.83	12.57	105.5	81	218	86.7	0.41	7.00	54.5	45	165	
8	3.96	12.93	124.5	89	212	90.0	0.38	6.98	49.5	44.5	160	
9	3.81	12.51	119.0	82	180	86.3	0.38	7.00	46.8	38	159	
10	3.95	12.73	134.0	87	198	85.3	0.45	7.09	54.3	45	177	
11	3.39	12.03	125.0	83	199	88.3	0.34	6.89	53.5	42	180	
12	3.97	12.66	121.5	80	204	86.8	0.36	6.99	51.5	43	133	
Lot No.	Press whey						Cheese (1 day old)					
	Yield	Fat	T.S.	Ca	P	Ribo.	Yield	Fat	T.S.	Ca	P	Ribo.
	*	*	*	**	**	***	*	*	*	**	**	***
1	0.42	1.20	15.7	215	132	126	10.28	37.4	67.3	782	462	452
2	0.44	2.47	20.0	248	130	137	9.37	35.1	66.1	756	460	396
3	0.54	4.45	21.1	225	118	161	9.08	34.8	65.8	728	444	401
4	0.52	2.72	18.8	225	126	159	9.74	33.2	65.3	800	508	440
5	0.53	1.50	16.7	301	146	176	9.98	35.5	66.2	736	460	497
6	0.56	3.39	19.1	297	148	188	10.36	34.5	66.0	740	440	468
7	0.38	4.78	19.5	258	139	184	9.45	35.2	66.5	632	424	468
8	0.60	1.51	16.1	273	148	198	9.88	35.85	67.1	824	500	538
9	0.51	2.31	18.0	213	104	192	9.62	35.3	66.7	808	480	600
10	0.47	1.34	19.6	217	123	190	9.54	35.3	65.9	828	452	490
11	0.53	1.98	21.2	190	97	194	8.93	33.9	65.8	876	480	497
12	0.59	1.43	17.5	161	87	175	9.87	36.6	66.9	776	468	475

* In percent. ** In mg. %. *** In micrograms per 100 g.

TABLE 11.—CHANGES IN FAT AND TOTAL SOLIDS CONTENT OF CHEESE DURING RIPENING

Values in per cent.

No.	40° F.									
	Age—mo.	$\frac{1}{2}$	1	2	3	4	6	8	10	12
1	Fat	38.2	38.3	38.2	38.5	38.7	39.9	39.9	39.5	39.2
	T.S.	69.1	68.8	68.6	68.8	70.2	71.4	72.1	72.2	71.2
2	Fat	35.6	36.2	35.8	36.3	36.5	36.6	36.8	36.9	37.3
	T.S.	66.3	66.9	66.8	67.8	68.1	68.2	69.1	69.2	69.5
3	Fat	35.2	35.1	35.6	35.9	35.8	36.3	35.7	36.0	36.1
	T.S.	65.8	66.2	69.6	67.6	67.8	69.6	69.1	68.5	68.8
4	Fat	33.9	35.5	34.4	34.6	34.5	35.8	36.3	36.2	35.6
	T.S.	65.9	66.7	66.4	66.7	66.8	69.7	71.1	70.8	69.6
5	Fat	35.7	36.2	36.4	36.6	37.4	36.9	36.5	37.1	37.2
	T.S.	66.8	67.2	67.6	68.4	69.9	69.4	68.3	70.4	70.1
6	Fat	35.4	35.4	35.6	35.6	36.2	36.2	35.6	35.9	36.6
	T.S.	66.4	66.8	67.5	67.9	69.0	68.8	67.8	68.6	70.0
7	Fat	36.1	36.0	36.1	36.3	36.8	36.9	36.9	—	37.0
	T.S.	68.2	67.3	68.0	68.2	70.0	70.0	69.9	—	69.6
8	Fat	36.5	36.4	36.8	36.4	37.0	36.5	37.3	39.0	39.9
	T.S.	68.6	68.5	69.0	68.9	69.2	69.2	70.2	73.2	72.5
9	Fat	36.0	36.4	36.2	36.3	36.2	36.3	36.4	36.6	38.4
	T.S.	68.2	69.0	68.5	68.6	68.5	68.4	69.1	69.3	73.1
10	Fat	35.7	36.3	36.2	36.4	36.5	36.4	36.5	38.4	38.2
	T.S.	67.0	67.7	67.2	67.3	68.0	68.4	68.0	72.3	70.7
11	Fat	34.1	34.5	34.1	34.2	34.4	34.2	34.5	39.0	36.2
	T.S.	66.4	66.6	66.1	66.4	67.0	66.6	66.5	72.8	72.4
12	Fat	37.2	37.5	37.4	37.5	37.9	38.3	38.3	38.2	38.6
	T.S.	67.9	68.7	68.6	67.6	69.2	69.7	69.7	69.8	71.2

No.	58° F.									
	Age—mo.	$\frac{1}{2}$	1	2	3	4	6	8	10	12
1	Fat	—	38.6	38.6	38.8	39.5	39.7	39.6	39.5	41.1
	T.S.	—	69.5	69.3	69.7	71.6	71.7	71.7	72.6	75.6
2	Fat	35.7	36.2	36.4	37.5	36.9	37.1	38.9	38.1	37.6
	T.S.	66.6	67.2	67.9	69.7	69.1	69.5	73.6	71.5	70.9
3	Fat	35.1	35.5	35.8	36.2	35.8	36.9	36.0	37.0	36.9
	T.S.	66.3	66.7	67.9	68.2	67.4	70.2	69.1	70.6	70.9
4	Fat	33.9	34.3	35.6	34.7	35.4	36.4	35.4	36.0	35.7
	T.S.	66.1	66.6	67.0	67.4	68.8	71.9	69.5	71.3	71.3
5	Fat	35.9	36.4	36.7	36.7	38.1	37.9	37.5	37.3	37.4
	T.S.	67.4	67.7	68.3	69.0	72.2	71.6	70.4	71.0	70.9
6	Fat	35.7	35.4	35.6	36.9	36.3	36.2	37.3	36.5	37.1
	T.S.	67.2	67.4	68.9	70.1	69.6	69.3	72.0	70.2	71.6
7	Fat	35.8	35.9	36.2	36.7	36.4	37.0	37.9	—	39.3
	T.S.	68.2	68.1	68.3	69.3	69.8	69.8	71.9	—	74.9
8	Fat	36.8	36.4	36.8	37.1	36.8	38.8	38.3	38.2	38.5
	T.S.	69.1	68.4	69.3	70.0	70.4	73.2	72.8	72.3	73.0
9	Fat	36.0	36.6	36.4	36.5	36.6	36.7	37.0	37.2	39.2
	T.S.	68.4	69.1	68.8	68.9	69.3	70.2	70.6	70.8	75.1
10	Fat	36.1	36.7	36.1	35.9	37.8	37.1	36.9	38.8	39.3
	T.S.	67.8	68.6	67.8	67.3	71.3	69.6	68.9	73.3	73.7
11	Fat	34.6	34.5	34.0	34.1	34.6	34.4	34.8	36.6	37.4
	T.S.	66.8	66.6	66.4	66.5	67.4	67.4	67.4	67.8	73.0
12	Fat	37.1	37.1	37.6	37.7	37.7	38.7	38.6	39.2	40.8
	T.S.	68.4	69.1	69.3	67.7	69.4	71.3	71.2	71.4	74.7

TABLE 12.—CHANGES IN RIBOFLAVIN CONTENT OF CHEESE DURING RIPENING

Micrograms per 100 g. of cheese

Lot No.	40° F.								
	Age—mo. $\frac{1}{2}$	1	2	3	4	6	8	10	12
1	397	388	386	401	448	449	477	497	510
2	389	393	393	456	444	468	493	472	513
3	417	420	458	424	430	478	489	478	563
4	471	451	456	478	478	498	460	506	542
5	—	434	443	477	489	490	495	491	486
6	436	471	470	487	483	472	518	506	561
7	460	466	440	480	485	493	473	—	577
8	497	490	477	480	468	519	510	561	551
9	482	470	449	436	468	458	490	543	482
10	497	486	480	490	514	461	448	589	498
11	470	460	478	495	450	480	488	456	496
12	430	475	436	451	468	494	490	482	509
	58° F.								
	Age—mo. $\frac{1}{2}$	1	2	3	4	6	8	10	12
1	391	318	361	377	432	480	469	—	509
2	403	352	381	447	448	459	482	486	509
3	413	399	458	431	417	466	485	481	562
4	460	435	461	469	471	483	430	509	546
5	—	396	429	468	471	492	491	490	494
6	435	469	461	487	475	464	509	519	535
7	441	473	445	478	475	490	474	—	571
8	492	487	475	469	467	509	517	545	545
9	467	469	451	436	445	470	476	530	500
10	495	489	479	479	513	468	445	580	493
11	466	462	471	490	454	487	476	462	494
12	427	474	438	445	485	484	502	480	507

THE RETENTION OF NUTRIENTS IN CHEESE MAKING

II, THE EFFECT OF PASTEURIZATION OF THE MILK UPON THE RETENTION OF CALCIUM, PHOSPHORUS AND RIBOFLAVIN IN CHEDDAR CHEESE¹

O. R. IRVINE², L. R. BRYANT³, AND W. H. SPROULE⁴

Ontario Agricultural College, Guelph, Ontario

and

S. H. JACKSON⁵, A. CROOK⁶, AND W. M. JOHNSTONE⁷

Hospital for Sick Children, Toronto, Ontario

[Received for publication June 25, 1945]

In a previous publication (8) the efficiency of the cheddar cheese manufacturing process was reported on with respect to the retention of calcium, phosphorus and riboflavin. In that study raw milk was used exclusively. In view of the fact that pasteurization of cheese factory milk supplies is practised in some countries and is advocated by many public health authorities, it seemed advisable to determine whether pasteurization would affect the retention of these nutrients. A study has therefore been carried out comparing raw milk with milks pasteurized by the conventional holder method and by the high-temperature short-time method with regard to the effect of these heat-treatments upon nutrient retentions. The experiment was so designed that the effect of these methods of pasteurization could be compared with each other and with a raw milk control. Trials were run at intervals of two months during the period from May, 1942 to April, 1943. As in the previous study, cheeses from each vat were ripened at two temperatures, 40° F. and 58° F. Ripening was continued for only six months in this case, however.

IIISTORICAL

It is the intention of the authors to report on the effect of these two methods of pasteurization upon the yield and quality of cheese in a later paper. For that reason much of the literature relating to the effect of pasteurization upon cheddar cheese will not be reviewed here.

The effect of two different methods of pasteurization of the milk upon the mineral content of cheddar cheese has been investigated by Moir (12). Pasteurization yielded cheese of reduced calcium and phosphorus content and altered Ca./P ratio. In these studies, however, abnormal acidities during manufacture appear to have influenced mineral retentions. In their studies on pasteurized milk cheddar cheese, Dolby, McDowall and McDowell (2) secured mineral retentions similar to those reported by us (8) for raw milk cheddar cheese.

Holland and Dahlberg (4) have studied the effect of time and temperature upon some of the properties of milk. Their observations on the effect of heat treatment upon rennet coagulability and changes in the calcium

¹ Joint contribution from the Departments of Dairying and Chemistry, O.A.C. and Department of Pediatrics, Hospital for Sick Children, Toronto. Determinations for fat and total solids were made in the Dairy Chemistry Laboratory, O.A.C., while those for calcium, phosphorus and riboflavin were made at the Hospital for Sick Children.

²: ⁴ Lecturer and Professor, respectively, Dairy Department.

³ Associate Professor and Dairy Chemist, Chemistry Department.

⁵ Research Assistant in Chemistry.

⁶ ⁷ Technical Assistants, Department of Paediatrics' Research Laboratories.

phosphate are of interest here. Their data show that with holding periods of 10 minutes or more, the range between 160° and 180° F. is the critical one. They were unable to discern any change in the relative proportions of CaHPO_4 and $\text{Ca}_3(\text{PO}_4)_2$ brought about by heating at normal pasteurizing time temperature combinations or at temperatures up to 165° F. for periods up to 5 minutes. Mattick and Hallet (11) found no reduction in the amount of diffusible phosphorus at temperatures below 175° F. with a 30-minute holding period. They did observe, however, that with this holding time, temperatures above 125° F. produced a marked reduction in the diffusibility of the calcium salts.

As a result of their investigations Magee and Harvey (10) suggest that calcium salts in milk are changed from a soluble to a colloidal form by heat.

Holmes *et al* (5) and Houston, Kon and Thompson (7) have studied the effect of pasteurization of milk upon riboflavin stability and both agree that losses are negligible. The riboflavin in milk was found to be thermostable even at sterilizing temperatures by Henry and Kon (3) and by Houston, Kon and Thompson (7).

EXPERIMENTAL

This study was carried out by using split batches of milk, six experiments being run. In order that they might not be influenced by seasonal conditions and that the analyses could be staggered, an interval of two months was allowed between each experiment.

On each of these occasions, approximately 1800 pounds of milk was secured from the College herd and after being thoroughly mixed was divided into three equal lots. The first of these served as a raw control and was manufactured into cheddar cheese following the method previously mentioned (8). The second lot was pasteurized by the holder method at 143° F. for 30 minutes after which it was cooled to between 50-70° F. in the cooling section of an A.P.V. regenerative pasteurizer. An 80-gallon stainless steel Cherry-Burrell vat was employed for heating and holding this milk, care being taken to avoid excessively fast heating or overheating in this operation.

The third lot of milk was pasteurized by passing it through a 250-gallon per-hour A.P.V. regenerative pasteurizer, heating to 161° F. and holding for 16 seconds. Here again the milk was cooled to between 50-70° F. The cheese making process was begun with both types of pasteurized milk immediately after pasteurization. Samples of milk plus starter were taken before renneting from each of the vats. While slight modifications have to be made in the method of manufacture when pasteurized milk is used, the method followed in this study was very similar to that for the parallel vats of raw milk cheese.

Samples of "first" whey and "press" whey were again taken, all the wheys being collected separately, and in this case weighed. The same procedure was also followed in taking the cheese samples except that the number was reduced and the ripening period was restricted to six months. The schedules of samplings for each series of vats is given in Table 1.

TABLE 1.—SCHEDULE FOR SAMPLING AND ANALYSES OF MILK, WHEY AND CHEESE

Analysis	Milk			First whey			Press whey		
	Raw	Hold	H.S.	Raw	Hold	H.S.	Raw	Hold	H.S.
Fat	X			X	X	X	X	X	X
T.S.	X			X	X	X	X	X	X
Ca.	X	X	X	X	X	X	X	X	X
P.	X	X	X	X	X	X	X	X	X
Ribo.	X	X	X	X	X	X	X	X	X

Analysis	Cheese (Raw, Hold and H-S)							
	Age—1 da.		14 da.		3 mo.		6 mo.	
	Temp.—40	58	40	58	40	58	40	58
Fat	X		X		X		X	
T.S.	X		X		X		X	
Ca.	X							
P.	X							
Ribo.	X	X	X	X	X	X	X	X

The methods of analysis employed in the project previously reported (8) were again used in this study.

RESULTS

In view of the possibility of certain variations in manufacturing technique exerting some effect upon the results obtained, especially on the retention of minerals, such values as the rates of starter, renneting acidities, etc. were carefully recorded. These are shown in Table 2.

TABLE 2.—DETAILS OF THE CHEESE MAKING PROCESS

Series	Date	Treat- ment	Starter	Milk ripening period	Setting acidity	Set to run	Running acidity	Run to salt	Rate of salt lb./1000 lb. milk
			%	min.	%	min.	%	min.	milk
P ₁	28/5/42	Raw	1.0	75	0.20	180	0.180	185	2.5
		Hold	1.0	91	0.19	194	0.165	180	2.5
		H-S	1.0	89	0.195	186	1.165	190	2.5
P ₂	28/7	Raw	1.0	72	0.18	205	0.175	120	2.25
		Hold	1.0	70	0.17	190	0.175	185	2.25
		H-S	1.0	70	0.18	210	0.18	195	2.25
P ₃	28/9	Raw	1.2	59	0.185	191	0.18	205	2.37
		Hold	1.2	45	0.175	180	0.17	180	2.37
		H-S	1.2	61	0.175	170	0.17	195	2.37
P ₄	25/11	Raw	1.6	90	0.18	160	0.185	175	2.25
		Hold	1.6	30	0.18	180	0.175	190	2.25
		H-S	1.6	55	0.17	165	0.17	180	2.25
P ₅	25/1/43	Raw	1.2	70	0.185	215	0.19	—	2.25
		Hold	1.2	70	0.165	200	0.165	—	2.25
		H-S	1.2	70	0.175	190	0.165	—	2.25
P ₆	25/3	Raw	1.0	46	0.18	226	0.185	180	2.25
		Hold	1.0	42	0.175	168	0.165	170	2.25
		H-S	1.0	49	0.18	171	1.165	180	2.25

Rennet extract was added at rate 3 fl. oz. per 1000 lb. of milk.

It will be noted that a lower running acidity was usually employed for the pasteurized milk vats. This is commonly the practice since it is possible to carry out the manufacturing process at lower acidity values. In addition, the titratable acidity of the milk is reduced slightly in pasteurization, particularly when the holder method is used.

Retention of Nutrients

Tables 9 and 10 in the Appendix show the data for fat, total solids, yield, calcium, phosphorus and riboflavin for each lot of milk plus starter, "first" whey, "press" whey and cheese. Table 11 gives the riboflavin values on the cheese throughout the ripening period and at the two temperatures.

Assessing the efficiency with which these nutrients are retained in the cheese has been done by expressing the proportion of the nutrient retained as a percentage of the amount originally present in the milk.

Calcium

The percentage values for the retention of calcium are presented below in Table 3 and in Figure 1.

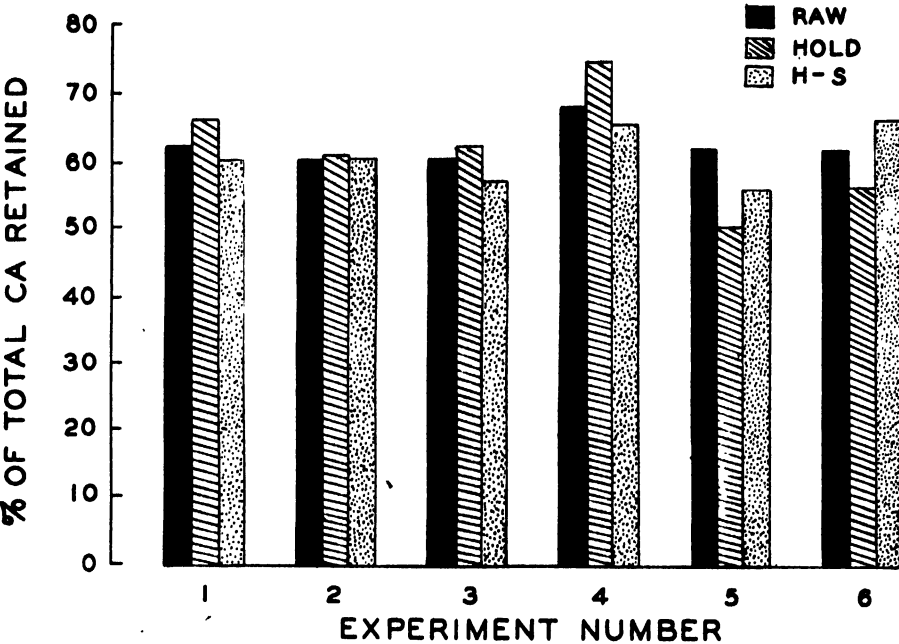


FIGURE 1. Effect of different heat treatments upon the efficiency of retention of calcium in cheese.

TABLE 3.—PERCENTAGE OF TOTAL CALCIUM RETAINED IN CHEESE

Series	Treatment of milk		
	Raw	Holder	High-Short
P ₁	62.70	66.80	60.53
P ₂	60.64	61.38	61.19
P ₃	61.12	63.02	57.80
P ₄	68.44	75.81	66.28
P ₅	62.38	50.91	56.70
P ₆	62.55	57.27	67.21
Mean	62.97	62.53	61.62

• It is quite apparent from these results that any difference produced by heat treatment of the milk upon the retention of calcium in the cheese is of no great significance. In general, the retention values are much more uniform for the raw milk curds than for those made from pasteurized milk.

A careful study of the values for calcium losses in the wheys as presented in the Appendix, will reveal that the sum of the calcium present in the whey plus that retained in the cheese is, in some instances, greater than the total amount originally present in the milk. In some instances also, the values obtained for the pasteurized milks are greater than for the corresponding raw milks. Errors of this character are not apparent in the case of fat, total solids, phosphorus or riboflavin. It must therefore be concluded that the method employed for the determination of calcium was less accurate than it should have been.

Phosphorus

Results for the retention of phosphorus have been compiled in a similar manner and are presented in Table 4 and Figure 2.

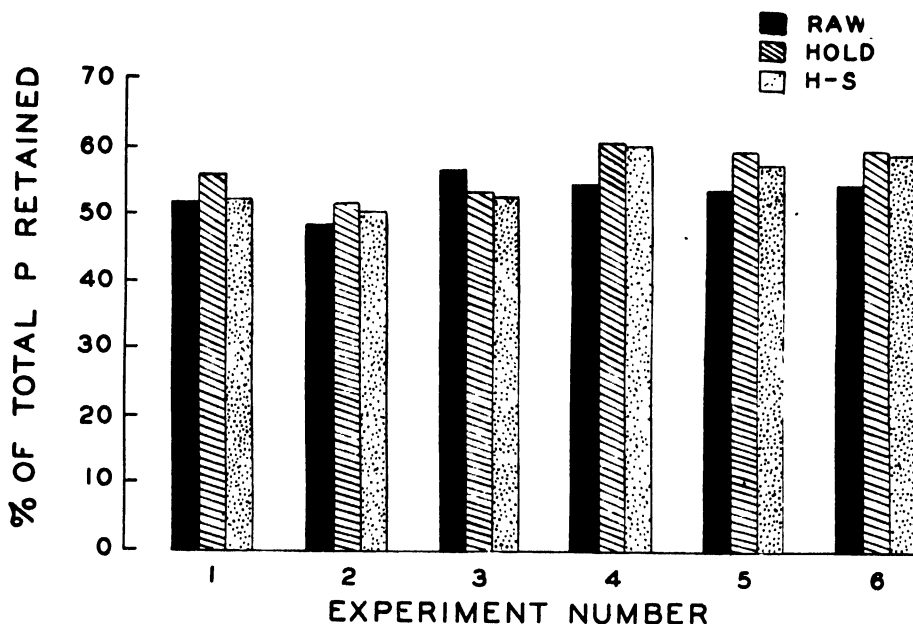


FIGURE 2. Effect of different heat treatments upon the efficiency of retention of phosphorus in cheese.

TABLE 4.—PERCENTAGE OF TOTAL PHOSPHORUS RETAINED IN CHEESE

Series	Treatment of milk		
	Raw	Holder	High-Short
P ₁	51.90	55.90	52.32
P ₂	48.35	51.81	50.54
P ₃	56.16	53.61	52.63
P ₄	54.31	60.88	60.18
P ₅	53.71	59.66	57.50
P ₆	54.40	59.94	59.57
Means	53.14	56.97	55.46

With the exception of one series, P_3 , the pasteurized milk cheese display a consistently higher rate of phosphorus retention. In view of this consistency it seems apparent that this result is a significant one.

Riboflavin

Special interest is attached to the retention of riboflavin in cheese making and also to any influence which pasteurization may have on these values.

The effect of pasteurization upon the destruction of this vitamin has been studied on several occasions. Reference to Table 9 will reveal the extent to which this vitamin was affected by heating in each trial. These results are summarized in Table 5.

TABLE 5.—EFFECT OF PASTEURIZATION ON THE DESTRUCTION OF RIBOFLAVIN IN MILK
($\mu\text{g.}/100\text{ g.}$)

	Treatment of milk		
	Raw	Holder	High-Short
Means of 6 trials	201.8	197.3	198.8

The differences between these means are very small and are typical of the results that have been reported by Holmes *et al.* (5). All three values, however, appear to be higher than those appearing in a recent compilation by Booher, Hartzler and Hewston (1).

The losses and retentions of riboflavin are set forth in Table 9. The efficiency with which the riboflavin was carried over into the one-day-old cheese is more readily understood when calculated as percentages of that originally present in the milk. These percentages are given in Table 6.

TABLE 6.—PERCENTAGE OF THE TOTAL RIBOFLAVIN RETAINED IN CHEESE

Series	Treatment of milk		
	Raw	Holder	High-Short
P_1	21.60	20.29	22.38
P_2	20.06	19.52	18.35
P_3	24.62	24.81	24.74
P_4	22.60	21.53	22.48
P_5	33.04	22.14	22.32
P_6	22.55	25.97	24.80
Means	24.08	22.38	22.51

Attention is directed to the value 33.04% as given for P_5 raw milk. Reference to Table 9 in the Appendix shows that this sample of cheese at one day contained 706 $\mu\text{g.}/100\text{ g.}$ of riboflavin as compared with 484 and 478 in the holder and high-short samples. This assay on the raw-milk cheese was repeated six times but an abnormally high value was always

obtained. At later stages of ripening this cheese displayed values ranging from 422 to 484 $\mu\text{g.}/100\text{ g.}$ It would seem logical therefore, that this result is an aberrant one and should not be included in the calculation of this mean. There are a number of factors which might have produced this erroneous result, chief of which would be that the cheese sample became contaminated with riboflavin producing micro-organisms (13).

If the value in question be deleted for purposes of calculating the mean, the remaining five values yield a mean of 22.28%. If this deletion is justifiable, one may conclude that the retention of riboflavin is not affected by the heat treatment which the milk receives.

Stability of Riboflavin During the Ripening Period

In conformity with the practice of Booher, Hartzler and Hewston (1), riboflavin values were calculated in micrograms per 100 grams of food. As was found to be the case in our previous study, however, variations in total solids content from one sample to another and even in the same lot of cheese at different stages of ripening, are likely to be considerable. The shrinkage which took place in the cheese ripened at 40° F. is illustrated in Table 7 and Figure 3.

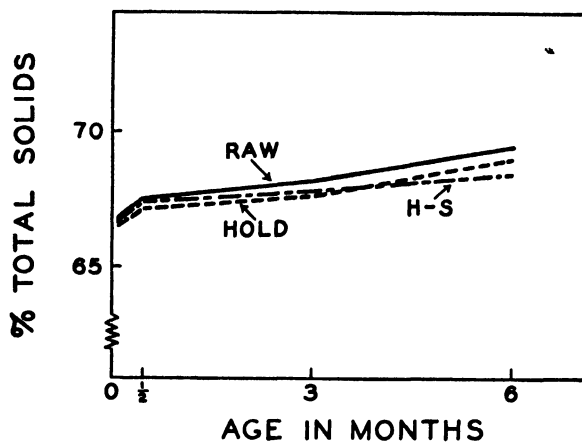


FIGURE 3. Increase in the total solids content of cheese during ripening.

TABLE 7.—AVERAGE TOTAL SOLIDS CONTENT OF CHEESE SAMPLES AT INTERVALS DURING RIPENING AT 40° F.

Age of cheese	Treatment of milk		
	Raw	Holder	High-Short
1 day	66.65	66.30	66.67
14 days	67.63	67.29	67.51
3 months	68.24	67.88	67.95
6 months	69.49	69.02	68.84

This gradual increase in total solids content tends to distort the picture of riboflavin stability unless corrections are made for these changes. In order to avoid this error the riboflavin values have been recalculated to

a 35% moisture content basis. The individual values for riboflavin on the cheese ripened at 40° and 58° F. are given in Table 11 while the means of the corrected values for the cheese ripened at 40° F. are shown in Table 8 and Figure 4. Similar results for the cheese ripened at 58° F. could not be calculated since it was not possible to secure results for total solids on these cheese.

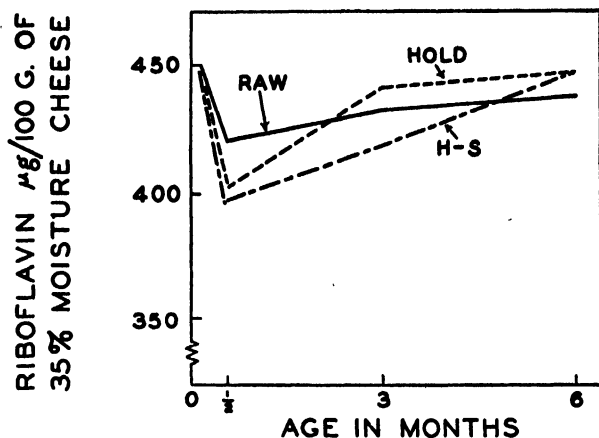


FIGURE 4. Variations in riboflavin content of cheese during ripening. Averages of six lots.

TABLE 8.—AVERAGE STABILITY OF RIBOFLAVIN DURING RIPENING. VALUES ARE EXPRESSED IN µG. OF RIBOFLAVIN PER 100 G. OF 35% MOISTURE CHEESE

Age of cheese	Treatment of milk		
	Raw	Holder	High-Short
1 day	450	440	446
14 days	419	400	396
3 months	433	441	416
6 months	438	448	447

The most evident feature of the above presentation is that, although there are apparent changes in the vitamin content of the cheese during ripening, at the end of six months the riboflavin content is essentially the same as at the beginning of the period. It is also evident that pasteurization of the milk by either process has no deleterious effect upon the vitamin content of the ripened cheese.

The diminution in vitamin content which occurred at the 14-day period is much more marked than that observed in the previous study (8). It will be noted that the fluctuation is least in the case of the raw milk cheese.

DISCUSSION

In the pasteurization of milk for cheesemaking it is important that the time-temperature combination be such that the destruction of all pathogenic

bacteria^a be assured. The two combinations employed in this experiment are such that they would be readily approved by most public health authorities in North America. In the event that the Canadian cheese industry were to adopt pasteurization as a modification of its present method, these or similar standards would have to be met. Any alternative methods at less effective time-temperature combinations, would not be satisfactory from the point of view of the milk sanitarian.

Approved standards of heat treatment were therefore chosen in this study. While they are not at all drastic, the equilibria involved in the chemistry of cheese making is of such a character that it is sometimes seriously affected by minor factors. This is particularly true in regard to the retention of minerals.

The suggestion of Magee and Harvey (10) that the calcium salts are partially converted to a colloidal form would suggest that pasteurization of the milk would tend to increase the retention of this element in the cheese. McDowall and Dolby (9) have interpreted the activity at the surface of a curd cube on the basis of the existence of a Donnan equilibrium. The experimental evidence in this study does not indicate, however, that either of these postulations apply in restraining the loss of calcium from the curd into the whey.

The increased retention of phosphorus as a result of pasteurization was noted above. This increase is not great but it did occur consistently in all but one experiment. It is also apparent in the lower losses which occur in the whey from the pasteurized lots. In view of the rather meagre information regarding the phosphorus compounds of milk and the effect of heat upon them, it is impossible to suggest any explanation for this. Nutritionally the extra phosphorus retained in the pasteurized milk cheese is of no great importance.

The retention values for riboflavin in the pasteurized milk cheese are of the same order as those reported in the authors' previous study on raw milk cheese (8) and agree with the findings of Houston and Kon (6). It is apparent from these results that pasteurization of the milk by either process has no adverse effect upon the retention of the vitamin. The riboflavin content of cheese is of such magnitude that this food is almost in a class by itself as a source of this vitamin. The high loss of this factor in the whey, however, presents a challenge either to find a method of utilizing it to better advantage in animal feeds or retaining more of it in the cheese. Comments on the latter possibility were made in the previous paper.

Riboflavin proved to be as stable in pasteurized milk cheese as in that made from raw milk although during the early stages of ripening a marked reduction was noted in these values. This reduction appeared more marked in both lots of pasteurized cheese than in the raw milk cheese. The evidence suggests that this recession was not an actual one and that the microbiological method of estimating riboflavin may be influenced by changes which occur in the bacterial flora of cheese and which take place concurrently with this apparent recession in riboflavin content. At the conclusion of the ripening period of six months the riboflavin values were equal to, or slightly in excess of, the original values found in the one-day-old cheese.

SUMMARY

The effect of pasteurizing milk for cheese manufacture by the holder and high-temperature short-time methods has been studied in comparison with cheese manufactured from raw milk from the point of view of the relative efficiency with which the calcium, phosphorus and riboflavin present in the milk were retained in the cheese.

The results indicate that heat treatment of the milk did not affect noticeably the retention of calcium.

Cheese made from pasteurized milk tended to retain slightly more of the phosphorus than did cheese made from raw milk.

Pasteurization by either method had no significant effect upon the retention of riboflavin when compared to the raw control.

A marked reduction in riboflavin content appeared to take place during the first 14 days of ripening. This reduction was followed by an equivalent increase with the result that the final values at the end of six months ripening were about equal to those found in the fresh cheese.

REFERENCES

1. BOOHER, LELA A., EVA R. HARTZLER and ELIZABETH M. HEWSTON. A compilation of the vitamin values of foods in relation to processing and other variants. U.S.D.A. Cir. No. 638. 1942.
2. DOLBY, R. M., F. H. McDOWALL and A. K. R. McDOWELL. Studies on the chemistry of cheddar cheese-making. V. Factors influencing the acidity and mineral content of cheese. *Jour. Dairy Res.* 8 : 1; 31. 1937.
3. HENRY, K. M., and S. K. KON. Effect of commercial sterilization on the nutritive value of milk. IV. Effect on the vitamin B complex, on vitamin B₁ and on vitamin B₂ (flavin) of milk. *Jour. Dairy Res.* 7 : 1; 22. 1938.
4. HOLLAND, R. F., and A. C. DAHLBERG. The effect of time and temperature of pasteurization upon some of the properties and constituents of milk. N.Y. Agr. Expt. Sta. (Geneva) Tech. Bul. No. 254. 1940.
5. HOLMES, A. D., C. P. JONES, A. W. WERTZ, and J. W. KUZMESKI. The ratio of ascorbic acid, riboflavin, and thiamin in raw and pasteurized milk. *Jour. Nutr.* 26 : No. 4 : 337. 1943.
6. HOUSTON, J., and S. K. KON. Reported by H. D. Kay. Cheese: some recent chemical and physico-chemical findings. *Chem. & Ind.* 60 : 411. 1940.
7. HOUSTON, J., S. K. KON, and S. Y. THOMPSON. The effect of commercial pasteurization and sterilization on the vitamin B₁ and riboflavin content of milk as measured by chemical methods. *Jour. Dairy Res.* 11 : 1; 67. 1940.
8. IRVINE, O. R., L. R. BRYANT, W. H. SPROULE, S. H. JACKSON, A. CROOK, and W. M. JOHNSTONE. The retention of nutrients in cheese-making. I. The retention of calcium, phosphorus and riboflavin in cheddar cheese made from raw milk. *Sci. Agr.* 25 : 12; 817-831. 1945.
9. McDOWALL, F. H. and R. M. DOLBY. Studies on the chemistry of cheddar cheese-making. IV. The existence of a Donnan equilibrium between curd and whey. *Jour. Dairy Res.* 7 : 2; 156. 1936.
10. MAGEE, HUGH EDWARD, and DOUGLAS HARVEY. Studies on the effect of heat on milk. V. Some physico-chemical changes in milk by heat. *Biochem. Jour.* 20 : 873. 1926.
11. MATTICK, ELFREIDA C. V., and HOWARD S. HALLET. Effect of heat on milk. A. On the coagulability by rennet. B. On the nitrogen, phosphorus and calcium content. *Jour. Agr. Sci.* 19 : 452. 1929.
12. MOIR, GEORGE M. Pasteurized milk for cheddar cheese-making. II. The mineral content of cheddar cheese. *Jour. Dairy Res.* 2 : 2; 176. 1931.
13. TITTSLER, RALPH P., and EARLE O. WHITTIER. The synthesis of riboflavin in symbiosis. *Jour. Bact.* 42 : 151. 1941.

APPENDIX

TABLE 9.—FAT, TOTAL SOLIDS, CA., P, AND RIBOFLAVIN IN MILK, FIRST WHEY, PRESS WHEY AND ONE-DAY-OLD CHEESE

Lot	Treatment	Milk					First whey						
		Fat	T.S.	Ca.	P	Ribo.	Yield	Fat	T.S.	Ca.	P	Ribo.	
		%	%	mg. %	mg. %	μg/100g.	%	%	%	mg. %	mg. %	μg/100g.	
P ₁	Raw Hold H-S	4.26	13.14	129.5	96.0	193	86.9	0.37	6.91	56.2	51.5	133	
						191	87.2	0.42	7.15	48.0	48.2	138	
						202	86.9	0.35	7.00	47.5	49.5	137	
P ₂	Raw Hold H-S	3.39	12.20	112.5	83.0	211	88.8	0.29	6.82	48.8	44.5	139	
						193	88.1	0.28	6.82	47.8	45.0	130	
						199	89.0	0.27	6.79	49.5	46.0	148	
P ₃	Raw Hold H-S	4.15	13.12	123.5	85.0	196	87.9	0.40	7.21	54.0	48.0	154	
						187	87.4	0.38	6.97	52.3	45.0	142	
						187	89.2	0.38	6.81	53.3	45.5	147	
P ₄	Raw Hold H-S	3.76	12.38	108.0	83.0	199	86.5	0.33	6.75	50.5	45.5	148	
						216	86.8	0.33	6.66	43.8	42.8	144	
						206	85.3	0.27	6.59	49.3	44.0	142	
P ₅	Raw Hold H-S	3.81	12.82	123.0	84.0	206	87.7	0.39	7.02	47.3	42.0	177	
						207	85.9	0.54	7.09	42.2	37.5	178	
						206	87.5	0.29	6.80	45.4	41.5	175	
P ₆	Raw Hold H-S	3.72	12.54	133.5	87.0	206	86.9	0.37	6.84	50.8	43.5	150	
						190	87.5	0.345	6.88	56.5	42.5	180	
						193	87.5	0.33	6.86	46.5	41.0	166	
Lot	Treatment	Press whey						Cheese (1-day-old)					
		Yield	Fat	T.S.	Ca.	P.	Ribo.	Yield	Fat	T.S.	Ca.	P.	Ribo.
		%	%	%	mg. %	mg. %	μg/100g.	%	%	%	mg. %	mg. %	μg/100g.
P ₁	Raw Hold H-S	0.25	1.44	16.9	229	130	144	10.06	37.0	67.2	808	496	415
		0.56	2.54	17.0	174	100	164	10.31	36.7	66.7	852	488	376
		0.51	1.68	16.5	199	112	164	10.44	37.1	67.2	748	472	433
P ₂	Raw Hold H-S	0.53	2.45	20.0	207	110	165	9.12	33.0	66.1	748	440	464
		0.49	6.24	22.5	220	126	169	9.33	32.8	66.1	796	472	404
		0.43	3.54	20.9	217	126	172	9.04	33.5	66.9	748	492	404
P ₃	Raw Hold H-S	0.41	2.35	18.2	253	128	172	10.20	35.8	66.9	740	468	473
		0.41	3.25	19.4	268	136	165	10.30	35.8	66.3	764	468	450
		0.49	2.55	18.0	274	140	171	9.78	36.2	67.1	724	452	473
P ₄	Raw Hold H-S	0.53	2.33	16.9	234	134	184	9.55	34.9	66.4	774	472	471
		0.58	2.87	19.7	230	130	194	9.75	34.6	66.4	832	512	477
		0.53	2.75	17.0	243	126	184	9.75	35.3	66.3	784	500	475
P ₅	Raw Hold H-S	0.51	3.53	18.5	189	92	213	9.64	34.9	66.7	796	468	706
		0.32	2.61	17.5	142	76	192	9.47	33.5	65.5	672	504	484
		0.41	1.95	17.6	188	102	191	9.62	34.9	66.1	722	508	478
P ₆	Raw Hold H-S	0.55	1.59	18.7	223	100	194	9.62	35.1	66.7	868	492	483
		0.66	1.65	17.4	249	113	192	9.83	34.6	66.9	852	500	502
		0.62	1.17	19.9	199	110	194	9.93	34.9	66.5	836	480	482

TABLE 10.—CHANGES IN FAT AND TOTAL SOLIDS OF CHEESE DURING ' SIX MONTHS RIPENING AT 40° F.

Lot No.	Fat				Total solids		
	Age in months	$\frac{1}{2}$	3	6	$\frac{1}{2}$	3	6
	Treatment	%	%	%	%	%	%
P ₁	Raw	37.5	37.9	39.0	68.7	68.7	70.8
	Hold	37.1	37.1	38.9	68.3	67.7	70.4
	H-S	37.5	38.0	38.0	68.4	68.4	69.4
P ₂	Raw	33.4	35.6	33.9	66.4	67.2	68.7
	Hold	32.9	33.2	33.7	65.9	66.8	68.4
	H-S	33.2	33.4	34.0	65.6	66.4	67.6
P ₃	Raw	36.4	36.4	38.5	67.5	68.3	71.6
	Hold	36.0	36.7	38.5	67.1	68.6	72.2
	H-S	36.4	36.8	38.6	67.5	68.5	72.0
P ₄	Raw	35.6	36.1	36.2	67.3	69.1	69.0
	Hold	35.6	36.0	35.6	67.4	68.5	68.1
	H-S	35.8	36.3	36.2	67.4	68.8	68.4
P ₅	Raw	35.6	36.2	35.9	68.3	68.8	68.8
	Hold	34.6	34.6	34.8	68.0	68.7	68.2
	H-S	35.8	35.7	35.8	68.5	68.3	68.7
P ₆	Raw	35.4	35.3	35.9	67.7	67.3	68.0
	Hold	35.2	35.0	35.2	67.1	67.1	67.0
	H-S	35.6	35.3	35.7	67.7	67.3	67.0

TABLE 11.—STABILITY OF RIBOFLAVIN DURING RIPENING AT TWO TEMPERATURES
(Values in $\mu\text{g.}/100\text{ g.}$)

Lot	Treatment	Time and temperature of storage						
		1 day	14 days		3 months		6 months	
			40° F.	58° F.	40° F.	58° F.	40° F.	58° F.
P ₁	Raw	415	392	379	438	427	475	460
	Hold	376	276	288	378	348	454	459
	H-S	433	270	280	354	346	463	448
P ₂	Raw	464	394	386	495	492	469	461
	Hold	404	402	388	471	443	486	464
	H-S	404	393	380	445	428	481	479
P ₃	Raw	473	473	454	460	453	478	477
	Hold	450	451	436	493	486	490	486
	H-S	473	414	429	459	452	478	477
P ₄	Raw	471	421	431	475	470	481	481
	Hold	477	419	423	486	469	492	490
	H-S	475	422	415	445	444	484	487
P ₅	Raw	706*	465	459	417	402	442	450
	Hold	484	463	465	—	446	456	452
	H-S	478	478	477	451	446	467	461
P ₆	Raw	483	472	475	454	456	464	468
	Hold	502	476	477	468	467	477	470
	H-S	482	490	478	458	455	467	472
Means—								
Raw		462	439	431	455	450	468	466
Hold		449	415	413	459	443	476	470
H-S		458	411	410	435	429	473	471

*Not included in mean.

. THE RETENTION OF NUTRIENTS IN CHEESE MAKING

III. THE CALCIUM, PHOSPHORUS AND RIBOFLAVIN CONTENTS OF CREAM, COTTAGE, BRICK AND BLUE CHEESE

O. R. IRVINE³, L. R. BRYANT³, AND W. H. SPROULE⁴

Ontario Agricultural College, Guelph, Ontario
and

S. H. JACKSON⁵, A. CROOK⁶, AND W. M. JOHNSTONE⁷

Hospital for Sick Children, Toronto, Ontario

[Received for publication June 25, 1945]

One factor which tends to restrict interest in cheese as a component of Canadian diets is the relatively limited number of varieties of cheese offered to the consuming public. It is generally agreed that an increase in the numbers of types of cheese would facilitate the promotion of cheese sales and result in a more nutritious, and probably cheaper, source of food for large sections of the population. This has been the experience in the United States where the sale of several foreign types of cheese brought about a noticeable increase in the per capita cheese consumption during the decade prior to the war.

Most varieties of cheese are known to be excellent sources of protein and the majority are also good sources of vitamin A activity. Wide variations in the methods of manufacture, however, cause differences in composition. This is particularly true of the mineral content. In addition, comparatively little is known regarding the water-soluble vitamins present in these varieties. It was for these reasons that a project was planned to study the calcium, phosphorus and riboflavin present in some special varieties of cheese made under controlled conditions. The varieties studied consisted of cream, cottage, brick and blue. The effect of an appropriate storage or ripening period upon riboflavin stability was also included in the study.

HISTORICAL

The methods employed in the manufacture of almost any variety of soft or fancy cheese are much more varied than those for cheddar. Differences in manufacturing methods which involve variations in acidities are now known to affect greatly the retention of minerals in the cheese. Wode (16) pointed out this relationship and his findings have been confirmed by others (8, 9, 10).

McCammon, Caulfield and Kramer (8) have reported the mean calcium and phosphorus contents of cream cheese made in their laboratory as 0.075 and 0.091%, respectively. These appear to be the only values in the literature. For cottage cheese these authors report values ranging from 0.09 to 0.128% calcium and 0.134 to 0.186% phosphorus. Garrett (2) found mean values of 0.08% calcium and 0.230% phosphorus on 102 samples of commercially made cottage cheese.

¹ Joint contribution from the Departments of Dairying and Chemistry, O.A.C. and Department of Pediatrics Hospital for Sick Children, Toronto. Determinations for fat and total solids were made in the Dairy Chemistry Laboratory, O.A.C., while those for calcium, phosphorus and riboflavin were made at the Hospital for Sick Children.

^{2, 4} Lecturer and Professor, respectively, Dairy Department.

³ Associate Professor and Dairy Chemist, Chemistry Department.

⁵ Research Assistant in Chemistry.

^{6, 7} Technical Assistants, Department of Paediatrics' Research Laboratories.

The literature appears to contain no riboflavin values for these two varieties of cheese. No recorded values for calcium, phosphorus or riboflavin were found for brick cheese although the riboflavin values reported by Burkholder, Collier and Moyer (1) for Limburger cheese might be expected to be similar.

Stilton cheese is somewhat analogous to blue cheese in that it is mould-ripened. Values for calcium, phosphorus and riboflavin are on record for this variety. Mattick (10) reports calcium values of from 0.207 to 0.258% and phosphorus values of 0.247 to 0.340% in commercially made samples of this variety. Houston and Kon (4) reports riboflavin values of 2.30 to 3.50 μg per g. of Stilton cheese.

Certain types of fancy cheese which develop a surface slime during the ripening process were found by Burkholder, Collier and Moyer (1) to show marked increases in their content of B-complex vitamins. This increase was attributed to the biochemical changes brought about by the micro-organisms in the slime of the cheese.

EXPERIMENTAL

In this study four lots of each variety were manufactured. The 16 lots were all made during the period of May-July, 1943, the dairy herd of the Ontario Agricultural College serving as the source of the milk. Of these varieties, brick and blue are subject to ripening processes and sampling of these types was therefore done at intervals during these periods. Cottage and cream cheese are highly perishable and were therefore stored for only 7 and 14 days, respectively. In view of the fact that there might be changes in riboflavin content during this period, assays for this vitamin were repeated at the end of these times. Table 1 has been prepared to outline more clearly the plan of the study.

TABLE 1.—OUTLINE OF STUDIES ON SPECIAL VARIETIES OF CHEESE

Variety and Lot	Date	Schedule of analyses	
		Fat, T.S., NaCl, Ca, P, Ribo.	
Cream 1	4/6	Fresh cheese (Ribo. again at 14 days)	
Cream 2	10/6		
Cream 3	7/7		
Cream 4	8/7		
Cottage 1	1/6	Fresh cheese (Ribo. again at 7 days)	
Cottage 2	2/6		
Cottage 3	1/7		
Cottage 4	7/7		
Brick 1	8/6	Fat, T.S., Ca, P, Ribo.	Fat, T.S., NaCl, Ribo.
Brick 2	9/6	Milk, whey	*Cheese at 1, 14 da., 1 and 3 mo.
Brick 3	14/7	Milk, whey	*Cheese at 1, 14 da., 1 and 3 mo.
Brick 4	15/7	Milk, whey	*Cheese at 1, 14 da., 1 and 3 mo.
Blue 1	12/5	Milk, whey	*Cheese at 1, 14 da., 3 and 6 mo.
Blue 2	13/5		*Cheese at 1, 14 da., 3 and 6 mo.
Blue 3	29/6		*Cheese at 1, 14 da., 3 and 6 mo.
Blue 4	30/7		*Cheese at 1, 14 da., 3 and 6 mo.

* Analysis for Ca. and P. was carried out on 1-day-old cheese.

The method used in manufacturing the cream cheese was similar to that described by Roundy and Price (12), the cheese being made from 16% cream pasteurized at 143° F. for 30 minutes and homogenized at 1500 lb. pressure. Starter was used at the rate of 5% and rennet at the rate of 3 ml. per 1000 lb. During the 14 days storage period at 40° F. the cheese was held in 4 oz. glass jars.

In manufacturing the cottage cheese curd, the method outlined by Mull, Reid and Arbuckle (11) was followed. In each lot, skim milk pasteurized at 143-145° F. for 30 min. was used; starter and rennet were added at the rate of 10% and 1.25 ml. per 1000 lb., respectively; and the curd was creamed on the morning following manufacture by stirring in enough 20% cream to give the cheese a fat content of about 4%. Salt was added at the rate of 1%. Samples were held in 12 oz. paraffined paper tubs during the 7-day storage period at 40° F.

The methods described by Wilson and Price (14) were largely followed for the brick cheese. Raw, warm, morning's milk was used exclusively. Lactic starter was added at the rate of 0.1% and rennet at the rate of 4 oz. per 1000 lb. Salt was added to these cheese by the dry method, rubbing it on all surfaces of the loaves on the first and second day following manufacture. One of the four lots could hardly be considered as being of even fair quality but this did not appear to affect the results of the trial. In this case the starter was inactive and the cheese developed a very gassy flavour and texture.

In the case of the blue cheese the first and third lots were made from raw milk according to the methods of Goss, Nielson and Mortensen (3) and Irvine (5) while raw, homogenized milk was used in the remaining two experiments. In the latter cases the method of Lane and Hammer (7) was employed. The mould powder used was purchased from the Department of Dairy Industry of the Iowa State College.

The brick cheese were ripened for the first two months at 58° F., being paraffined after the first two weeks. Storage for the remainder of the ripening period was at 40° F. The blue cheese was held at 50° F. for the first three months under conditions of high relative humidity. During this period they were scraped three times to remove excessive slime growth after which the cheese were tightly wrapped in tin foil and transferred to the 40° F. storage.

The problem of securing a representative sample of a substance like cream or cottage cheese is a difficult one. In the case of the cream cheese the curd was allowed to continue draining overnight at 40° F. The salt was then added and thoroughly worked in, after which three sub-samples were taken and thoroughly mixed together. A similar plan was followed in the case of the cottage cheese. For brick cheese, a quarter of a loaf was removed and split lengthwise in the manner in which a print of butter is sampled. In sampling the blue cheese a 45-degree wedge was removed from a cheese for analysing. This was subdivided into four pieces, two of which were wrapped in moisture-proof "Cellophane" and dispatched to each laboratory.

The methods of analysis for fat, total solids, calcium, phosphorus and riboflavin were those cited in a previous paper (6). Sodium chloride was determined according to the method described by Wilster *et al.* (15).

RESULTS

Cream Cheese

Table 2 indicates the results secured on this type of cheese.

TABLE 2.—CA, P, AND RIBOFLAVIN PRESENT IN CREAM CHEESE

Lot	Fat	T.S.	NaCl	Ca	P	Riboflavin	
						1 da.	14 da.
	%	%	%	mg. %	mg. %	μg/100 g.	μg/100 g.
1	41.99	52.00	—	82.4	86	265	320
2	39.19	49.24	—	86.4	86	323	325
3	32.30	42.04	1.53	—	—	273	251
4	42.91	52.53	1.13	—	—	260	267
Mean	39.07	49.70	—	—	—	280	291

It will be noted that lot No. 3 is above the legal limit for moisture content according to the Dairy Industry Act. Aside from this these lots of cheese were all quite typical of the product usually offered for sale. The high moisture content is one factor which contributes to the relatively low values for calcium and phosphorus but it is obvious that this variety is not equal to cheddar cheese as a source of these minerals. The results for riboflavin suggest that this vitamin suffers no destruction during a holding period of up to 14 days.

Cottage Cheese

Since a comparatively high acidity is developed in this process and since also the curd is usually subject to two or more washings, the values for nutrients are likely to bear little relationship to the nutrients originally present in the milk. For these reasons the values on the finished cheese only were determined. These are presented in Table 3.

TABLE 3.—CA, P, AND RIBOFLAVIN PRESENT IN COTTAGE CHEESE

Lot	Fat	T.S.	NaCl	Ca	P	Riboflavin	
						1 da.	7 da.
	%	%	%	mg./100 g.	mg./100 g.	μg/100 g.	μg/100 g.
1	3.18	20.31	0.75	87	137.6	293	260
2	3.09	20.63	0.95	89	140.0	—	288
3	1.71	21.15	1.05	79.2	161.6	317	276
4	2.58	19.97	1.02	—	—	251	308
Means	2.64	20.51	0.94	85	146	288	283

The relatively high moisture content of cottage cheese results in its lower nutritive value. On the basis of the mean values, riboflavin appears to be stable during this seven-day period.

Brick Cheese

As this variety was made from whole milk and the curd was not washed, it was possible to determine the values for nutrients in the milk,

whey and cheese and to assess the efficiency of the cheesemaking process with respect to retention of these factors. The results from the four vats have been averaged and are presented in Table 4. Table 8 in the Appendix gives the actual values for these nutrients and details of composition, etc.

TABLE 4.—LOSS IN WHEY AND RETENTION IN BRICK CHEESE OF CA, P, AND RIBOFLAVIN SHOWN AS PERCENTAGES OF THE AMOUNT ORIGINALLY PRESENT IN THE MILK

Means of four lots			
—	Ca	P	Riboflavin
	%	%	%
Whey	26.7	37.7	56.9
Cheese (1 da.)	57.7	58.7	27.4
Total	84.4	96.4	84.3

These results indicate that mineral retention in brick cheese is of the same order as in raw-milk cheddar cheese. In view of the fact that there is no development of acidity in this process even up until the time curds are placed in the forms, one would anticipate a slightly higher retention of calcium in the cheese. The retention of riboflavin in the one-day-old cheese is significantly higher than in cheddar cheese, however, due no doubt to the fact that the moisture content and yield of cheese is higher than cheddar.

The development of a surface slime on these cheese during early ripening is a factor which might alter the riboflavin content during this interval. Largely for this reason a study was made of riboflavin stability during the ripening period. Results (Table 5) have been recalculated to a 35% moisture basis in order to obviate the error caused by shrinkage.

TABLE 5.—STABILITY OF RIBOFLAVIN DURING THE RIPENING OF BRICK CHEESE. RESULTS CALCULATED ON A 35% MOISTURE BASIS

LOT	Riboflavin (μ g/100 g. 35% moisture cheese)			
	Age—1 da.	14 da.	1 mo.	3 mo.
1	598	550	473	485
2	632	600	504	474
3	682	520	507	508
4	624	550	546	564
Mean	634	555	508	508

These results indicate that after the first two or three weeks of ripening, riboflavin values are stable. During the period of slime formation and washing, however, there appears to be a significant loss of this factor.

Blue Cheese

In these experiments it was also possible to determine the percentages of nutrients lost and retained. The results are presented in Table 6 and in Table 9 in the Appendix.

TABLE 6.—LOSS IN WHEY AND RETENTION IN BLUE CHEESE OF CA., P., AND RIBOFLAVIN SHOWN AS PERCENTAGES OF THE AMOUNT ORIGINALLY PRESENT IN THE MILK

Means of four lots

—	Ca	P	Riboflavin
	%	%	%
Whey	46.1	48.1	58.5
Cheese (1 da.)	46.2	43.3	30.1
Total	92.2	91.4	88.6

High acidities are employed in blue cheese manufacture and these may account for the relatively poor retention of minerals in these trials. The values for calcium and phosphorus present in the cheese are much greater than those found in English Stilton by Mattick (10), however.

Values showing changes in riboflavin content during ripening have been calculated in the same manner as for brick cheese and are presented in Table 7.

TABLE 7.—STABILITY OF RIBOFLAVIN DURING THE RIPENING OF BLUE CHEESE. RESULTS CALCULATED ON A 35% MOISTURE BASIS

Lot	Age	Riboflavin (μ g/100 g. 35% moisture cheese)			
		1 da.	14 da.	3 mo.	6 mo.
1		614	615	560	630
2	(Homo.)	590	620	571	654
3		670	620	560	608
4	(Homo.)	720	610	574	599
Mean		649	616	566	622

The above values are the highest so far encountered for riboflavin in any cheese studied in this project. They also indicate that here again riboflavin is not adversely affected by any of the chemical changes which occur during cheese ripening. The practice of homogenizing the milk which was followed in the case of lots 2 and 4 appears to have had no adverse effect upon the riboflavin content of the cheese.

DISCUSSION

In so far as mineral values are concerned, these results confirm the findings of McCann, Caulfield and Kramer (8) to the effect that cheese of different varieties vary widely in mineral content. In the manufacture of those varieties in which high acidities are developed or in which the curds are washed with water, a marked reduction in calcium content particularly, is to be expected. Where these practices can be avoided or limited, the nutritive qualities of the cheese are benefited. Where cheese-making methods (e.g. cottage cheese) can be varied without affecting the

flavour and texture qualities of the product, the retention of additional nutrients should be a factor in determining what manufacturing procedure will be followed.

The mineral values on cream and cottage cheese, while indicating that these varieties are much poorer than the cheddar, brick and blue varieties, are still such that they rank very high in any list of calcium and phosphorus containing foods. The large proportion of these minerals retained by brick and blue cheese is a point which should highly recommend these varieties to dietitians.

These varieties all appear to be good sources of riboflavin, particularly brick and blue cheese. On the basis of their solids-not-fat content, cream and cottage cheese rate very well.

The results obtained in this study are not in accord with the findings of Burkholder, Collier and Moyer (1) in regard to increases occurring during the ripening periods of some semi-hard cheeses. On the other hand they agree with Sullivan, Bloom and Jarmol (13) who found riboflavin to be quite stable during ripening.

SUMMARY

A study has been made of the calcium, phosphorus and riboflavin contents of cream, cottage, brick and blue cheese. In the case of the latter two varieties, the proportions of these nutrients originally present in the milk which were retained in the cheese, were determined. In addition the stability of riboflavin during the ripening periods of brick and blue cheese was also studied. The average results on a limited number of batches were as follows:

Cream cheese contained 84.4 mg. % calcium, 86 mg. % phosphorus, and 280 μ g. per 100 g. of riboflavin:

Cottage cheese contained 85 mg. % calcium, 146 mg. % phosphorus and 288 μ g. per 100 g. of riboflavin:

In brick cheese, of the original nutrients present in the milk, 57.7% of the calcium, 58.7% of the phosphorus and 27.4% of the riboflavin were retained in the cheese.

In blue cheese the corresponding values for retention were: calcium, 46.2%; phosphorus, 43.3%; and riboflavin, 30.1%.

The riboflavin content of the cream and cottage cheese did not change when these varieties were stored for short periods. It also appeared to be quite stable in the ripening processes of brick and blue cheese.

REFERENCES

1. BURKHOLDER, PAUL R., JANE COLLIER, and DOROTHY MOYER. Synthesis of vitamins by micro-organisms in relation to vitamin content of fancy cheeses. *Food Res.* 8 : 14; 314. 1943.
2. GARRETT, O. F. The calcium and phosphorus content of commercially made cottage cheese. *Jour. Dairy Sci.* 26 : 4; 305. 1943.
3. GOSS, E. F., V. NIELSON, and M. MORTENSEN. Iowa Blue Cheese. *Iowa Agr. Expt. Sta. Bul. No. 324.* 1935.
4. HOUSTON, J., and S. K. KON. Reported by H. D. Kay. Cheese: Some recent, chemical and physico-chemical findings. *Chem. & Ind.* 60 : 411. 1940.

5. IRVINE, O. R. Canadian "Blue" Cheese. *Can. Dairy & Ice Cream Jour.* 17 : 11; 1. Oct. 1938.
6. IRVINE, O. R., L. R. BRYANT, W. H. SPROULE, S. H. JACKSON, A. CROOK and W. M. JOHNSTONE. The retention of nutrients in cheese-making. I. The retention of calcium, phosphorus and riboflavin in cheddar cheese made from raw milk. *Sci. Agr.* 25 : 12; 817-832. 1945.
7. LANE, C. B., and B. W. HAMMER. The manufacture of blue cheese from homogenized cow's milk. *Iowa State Coll. Jour. Sci.* 10 : 4; 391. 1936.
8. McCAMMON, R. B., W. G. CAULFIELD and M. M. KRAMER. Calcium and phosphorus of cheese made under controlled conditions. *Jour. Dairy Sci.* 16 : 3; 253. 1933.
9. McDOWALL, F. H., and R. M. DOLBY. Studies on the chemistry of cheddar cheese-making. I. The mineral content of cheese and whey. *Jour. Dairy Res.* 6 : 218. 1935.
10. MATTICK, E. C. V. The calcium and phosphorus content of some types of British cheese at various stages during manufacture and ripening. *Jour. Dairy Res.* 9 : 233. 1938.
11. MULL, L. E., W. H. E. REID and W. S. ARBUCKLE. The effect of standardizing the acidity in the manufacture of cottage cheese and cultured buttermilk. *Mo. Agr. Expt. Sta. Res. Bul.* 319. 1940.
12. ROUNDY, Z. D., and W. V. PRICE. The influence of fat on the quality, composition and yield of cream cheese. *Jour. of Dairy Sci.* 24 : 235. 1941.
13. SULLIVAN, R. A., E. BLOOM, and J. JARMOL. The value of dairy products in nutrition. III. The riboflavin, pantothenic acid, nictotinic acid, and biotin content of several varieties of cheese. *Jour. Nutr.* 25 : 5; 463. 1943.
14. WILSON, H. L., and W. V. PRICE. The manufacture of brick cheese. *U.S.D.A. Cir.* 359. 1935.
15. WILSTER, G. H., W. V. PRICE, O. F. MORRIS, E. F. GOSS, and G. P. SANDERS. Determination of fat, moisture and salt in soft cheese. *Jour. of Dairy Sci.* 23 : 197. 1940.
16. WODE, —. —. *K. Landtbr. Akad. Handl. Stockh.* 67, 1032. 1930. (Cited by Dolby, McDowall and McDowell, *Jour. Dairy Res.*, 7 : 1; 22. 1938.)

APPENDIX

TABLE 8.—DETAILED RESULTS* ON BRICK CHEESE

Lot No.	Milk					Whey				
	Fat	T.S.	Ca	P	Ribo.	Fat	T.S.	Ca	P	Ribo.
1	1.23	11.90	130.5	75	227	0.25	6.75	43.3	33.5	157
2	3.69	12.49	134.5	76	257	0.30	6.94	40.0	33	164
3	3.89	11.89	—	—	220	0.31	6.96	—	—	206
4	4.19	12.78	—	—	255	0.33	6.96	—	—	186

Cheese (one-day-old)

Lot	Yield	Fat	T.S.	Ca	P	Ribo.
1	11.21	27.6	55.2	728	432	508
2	12.14	28.9	55.3	640	420	538
3	12.19	30.1	55.8	—	—	585
4	13.07	31.4	55.3	—	—	530

Cheese

Lot	Age—14 da.				1 mo.				3 mo.			
	Fat	T.S.	NaCl	Ribo.	Fat	T.S.	NaCl	Ribo.	Fat	T.S.	NaCl	Ribo.
1	29.5	60.1	1.57	508	30.5	62.3	1.72	453	31.8	63.4	1.77	473
2	30.4	58.8	1.87	544	31.3	61.6	2.16	478	33.2	64.7	2.11	471
3	34.6	65.1	1.98	522	34.7	65.6	2.20	512	38.6	71.6	3.25	559
4	34.0	60.8	1.86	515	35.7	63.2	2.09	531	37.3	65.0	1.93	564

*Fat, T.S., NaCl. in percent.
Ca., P. in mg./100 g.
Riboflavin in μ g/100 g.

TABLE 9.—DETAILED RESULTS* ON BLUE CHEESE

Lot No.	Milk					Whey				
	Fat	T.S.	Ca	P	Ribo.	Fat	T.S.	Ca	P	Ribo.
1	4.42	13.24	128.5	86	208	0.37	7.00	70.3	49	154
2	4.08	12.53	128.5	86	332	0.32	6.84	64.8	47.5	165
3	4.13	12.84	129.5	82	256	0.32	6.79	37.8	47.5	170
4	3.86	12.46	118.5	82	280	0.30	6.87	—	—	192

Cheese (one-day-old)

Lot	Yield	Fat	T.S.	Ca	P	Ribo.
1	13.46	30.5	53.6	388	252	506
2	14.32	26.8	48.7	468	292	441
3	13.83	29.3	53.0	312	252	546
4	13.59	28.7	52.1	—	—	579

Cheese

Lot	Age—14 da.				3 mo.				6 mo.			
	Fat	T.S.	NaCl	Ribo.	Fat	T.S.	NaCl	Ribo.	Fat	T.S.	NaCl	Ribo.
1	31.4	57.1	2.81	541	39.1	67.4	4.31	577	39.2	68.3	4.08	663
2	27.9	53.8	4.33	513	35.2	64.0	4.81	564	33.8	66.4	6.05	668
3	30.4	55.7	2.79	530	42.4	73.1	4.05	646	40.8	73.0	4.35	683
4	29.9	56.8	3.20	532	39.6	72.5	4.59	640	40.3	75.1	4.28	693

* Fat, T.S., NaCl. in percent.
Ca., P. in mg./100 g.
Riboflavin in μ g/100 g.

GROWTH OF BACON TYPE HOGS¹

RATES OF GAIN AT SPECIFIC LIVE WEIGHTS

C. D. T. CAMERON,² G. C. ASHTON,³ S. A. HILTON,⁴ and E. W. CRAMPTON⁵

[Received for publication August 9, 1945]

Published data giving average growth rates of Canadian bacon type hogs are scant. Crampton (2) and, Ashton and Crampton (1) have published growth curves for bacon type hogs fed at Macdonald College, but these values may or may not represent pigs fed at other Canadian centres. To secure suitable data for such curves, management practices must provide live weight records of pigs at short intervals, and preferably not exceeding 14 days. While all Canadian stations do not record weights at such short intervals, a number of them do weigh their test pigs biweekly.

SOURCE AND NATURE OF THE DATA

The Dominion Experimental Farm at Nappan, N.S. follows the above mentioned procedure, with the result that in January, 1945, there were available at this Station biweekly live weight records for 183 group-fed hogs. In such data was material for the construction of a swine growth curve, about which individual variation could be indicated. Group treatment, however, prevents the collection of individual feed consumption data as well as a measure of the individual variation, so feed intake has not been considered in this study.

The hogs used in this study were of Yorkshire breeding. Their dams were bred at the Nappan Experimental Farm and were almost all daughters, grand-daughters, or great-grand-daughters of the Swedish-bred sire Valter of Svalof-179616-. Litters were farrowed in both early spring and fall, and creep-fed from 2 weeks of age. The males were castrated when one month old and all pigs were weaned at approximately 8 weeks.

The hogs were allotted to experimental feeding pens of 4 or 5 hogs each at 65-75 days of age. All groups were full hand fed the meal allowance, with water, thrice daily from weaning to an average weight of 100-125 pounds and thereafter twice daily.

The basal fraction of the rations for most of the pigs consisted of feed barley, oats and wheat or shorts. Barley generally constituted about 50% of the rations except for 25 hogs which received barley only as the basal feed.

White-fish meal constituted the entire protein supplement for the greater number of the hogs. In two tests involving 72 pigs, the protein-

¹ Contribution from the Division of Animal Husbandry, Dominion Experimental Farm, Nappan, N.S., and Nutrition Laboratory, Macdonald College (McGill University), Que.

Nappan Experimental Farm Journal Series No. 1.

Macdonald College Journal Series No. 207.

² Experimental Farm Assistant, Dominion Experimental Farm, Nappan, N.S.

³ Assistant in Animal Nutrition, Macdonald College, Que.

⁴ Experimental Farm Assistant, Dominion Experimental Farm, Nappan, N.S.

⁵ Professor of Animal Nutrition, Macdonald College, Que.

mineral supplement was made up as follows: Tankage 50%; white-fish meal 15%; linseed oilmeal 20%; bone meal 5%; ground limestone 5%; and salt 5%. A few hogs in one test were fed oily-fish meal, or tankage, as the protein supplement. A mineral mixture, made up of one meal 40%, ground limestone 40%, and salt 20%, was fed at 1-2% of the basal feed allowance to all hogs fed a single high protein feed.

The rations during the first period for all groups fed the mixed protein-mineral supplement consisted of 85 parts basal feeds and 15 parts supplement, while the proportion of supplement was reduced to about 10% in the last period. The various protein supplements used have not resulted in any appreciable difference in the estimated digestible protein content of the rations fed. The final feed mixtures were supplemented with one teaspoonful of cod liver oil daily for each animal in all groups under 100 pounds average weight.

TREATMENT OF DATA

The relating of daily gains of pigs to specific body weights requires data on live weights and interval live weight increases. The experimental method followed at Nappan of arranging many of the test pigs into groups of 5 precluded equal representation of the sexes on any one ration so no attempt was made here to determine these differences. The combining of the data from the two sexes is further warranted by the study of Ashton and Crampton (1) which showed the rate of gain to be statistically the same for male and female pigs of identical live weights.

The system of biweekly weighing practised at this Station provided, for each pig on test, several live weight records and consequently a number of 14-day and/or weight interval gains. Live weight values to correspond to average daily gain values over the time and/or weight intervals were taken as the midpoints between the two appropriate weighings. Thus for example the values for a pig whose live weights at successive periods were 151 pounds and 169 pounds are: average daily gain 1.3 pounds, and the midpoint or weight to which this gain value is applied is 160 pounds.

Following the determination of these midpoints and their respective daily gains, the latter were brought together at live weight intervals of 10 pounds. For example, all gains made at mid-weights from 155 to 164 pounds inclusive were put into the 160 pound group. The mean gain and the standard deviation were calculated for each live weight group. These values were then plotted against live weight and the resulting curves smoothed by Fisher's Summation Method of Fitting Polynomials (3).

RESULTS AND DISCUSSION

The tabulated values for the hogs in this study appear in Table 1 and their trend is graphically depicted in Figure 1 by a third degree polynomial.

TABLE 1.—AVERAGE DAILY GAINS AND THE STANDARD DEVIATIONS FOR YORKSHIRE PIGS FROM 30 TO 200 POUNDS LIVE WEIGHT

Weight classes	Average daily gain	
	Observed values	Third degree polynomial
lbs.	lbs.	lbs.
30	0.73 ± 0.15	0.72 ± 0.19
40	0.84 ± 0.21	0.88 ± 0.20
50	1.00 ± 0.28	1.02 ± 0.22
60	1.19 ± 0.27	1.14 ± 0.24
70	1.31 ± 0.28	1.24 ± 0.25
80	1.33 ± 0.32	1.33 ± 0.27
90	1.41 ± 0.26	1.40 ± 0.28
100	1.40 ± 0.35	1.45 ± 0.30
110	1.40 ± 0.24	1.50 ± 0.31
120	1.50 ± 0.25	1.54 ± 0.33
130	1.61 ± 0.29	1.58 ± 0.35
140	1.70 ± 0.31	1.61 ± 0.36
150	1.64 ± 0.37	1.64 ± 0.38
160	1.73 ± 0.42	1.68 ± 0.39
170	1.76 ± 0.36	1.72 ± 0.41
180	1.64 ± 0.37	1.77 ± 0.42
190	1.79 ± 0.50	1.82 ± 0.44
200	1.95 ± 0.56	1.90 ± 0.45

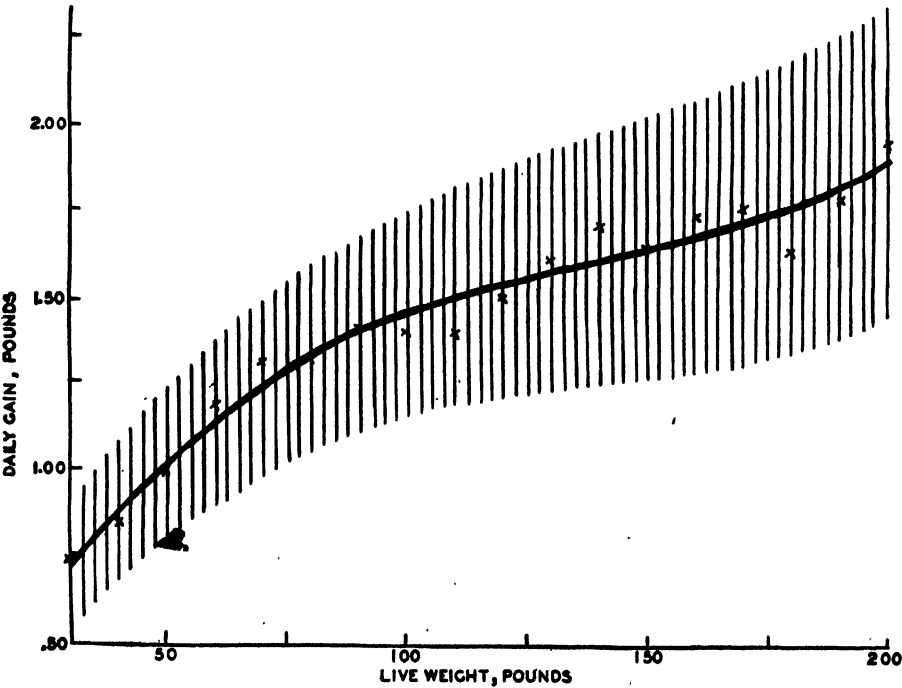


FIGURE 1. Average daily gain of Yorkshire pigs from 30 to 200 pounds live weight. Shaded area marks limits of ± one standard deviation.

A comparison of this curve with the one by Ashton and Crampton (1) appears in Figure 2. The curve in this study shows considerably less change in slope, and slower gains over the greater part of its length, than that from Macdonald. All of the mean gains but one (at 50 pounds) below 160 pounds are significantly different at odds of 19 : 1.

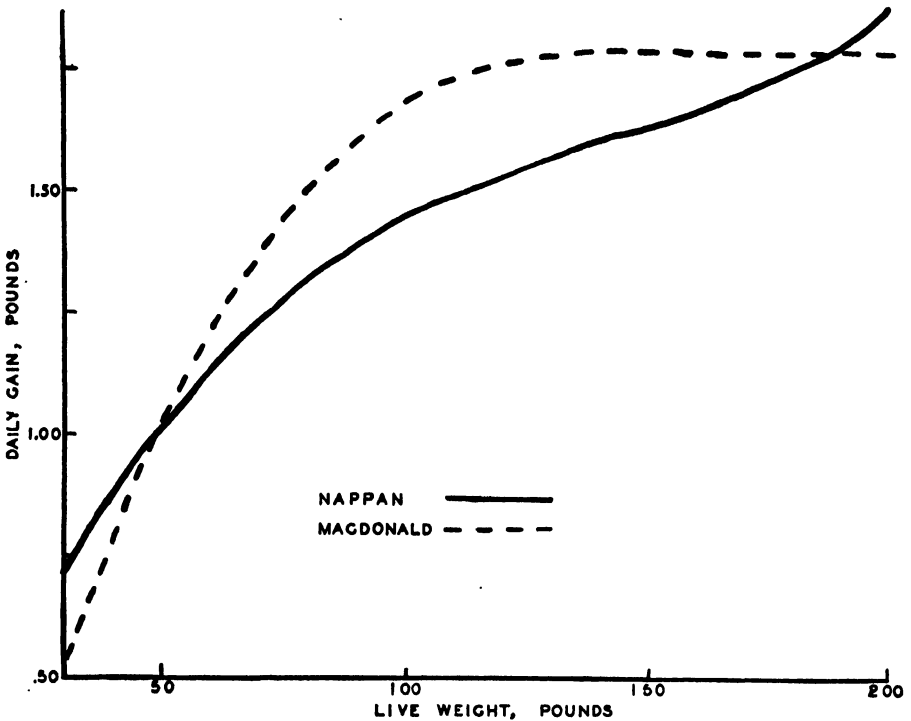


FIGURE 2. Average daily gain of pigs fed at Nappan and Macdonald.

It will be noted that the two curves cross one another at the 50-pound point and again at 185 pounds. The higher rate of gain for the small pigs at Nappan would appear to be the result of creep-feeding during the nursing period and probably to a lesser extent to the gradual change from stock to test rations.

Pigs reared at Macdonald College are not provided with creep feed but are encouraged to steal from the sow's trough. The sows receive a starter-grower mixture throughout their gestation and lactation period. Following weaning the young pigs continue to receive the same ration until they are placed on trial when they are immediately given their respective test rations in individual pens.

The accelerated rate of gain of the Nappan pigs over 185 pounds in weight does not appear to be the result of ration differences, since smoothed curves in Figure 3 based on other groups of hogs from these stations, whose treatment has been similar, show the same differences in trend as observed in Figure 2. The animals represented in Figure 3 were part of a co-operative feeding trial in which special efforts were made to standardize test

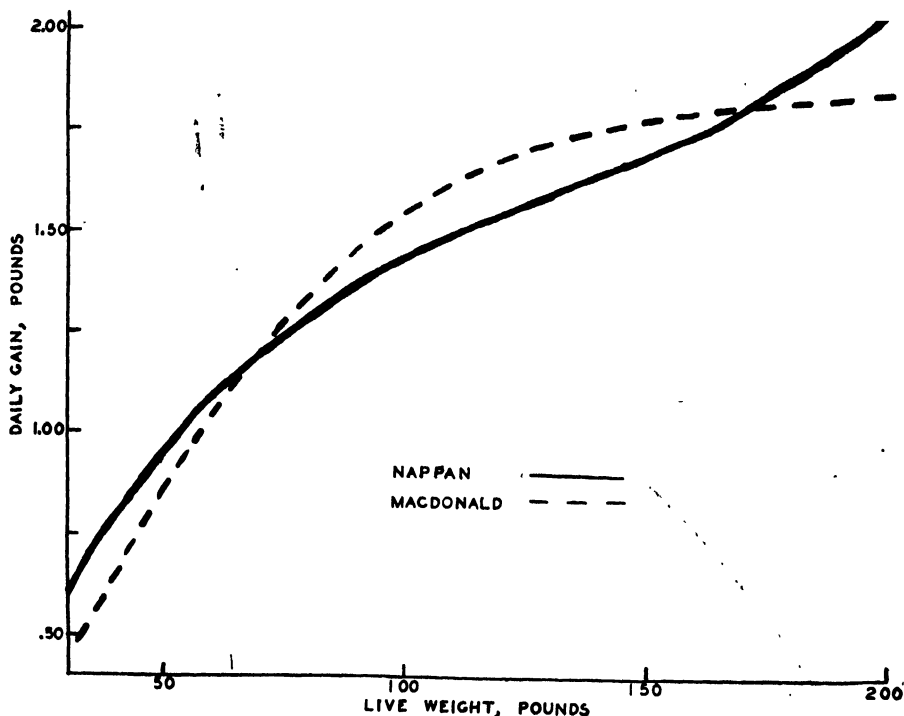


FIGURE 3. Average daily gain of Nappan and Macdonald fed pigs, receiving the same rations.

conditions at several feeding stations. The feed was prepared by a single commercial feed firm and distributed by it to all the stations at the same time. There is some Nappan blood in the Macdonald herd so the breeding is not greatly different. It would appear, therefore, that feeding management has been the cause of the difference in the shape of the curves.

A study of the live weights of all the animals in each group of the Nappan pigs disclosed a wide range in their weights at any particular time. In many instances when the average weight of the group was 100 pounds the lighter ones were only 80 pounds while the heavier ones were 120 pounds. Since this was the weight at which the protein in the feed was reduced, the change occurred late for the large pigs and early for the small ones. This gave a low protein intake for the small pigs in each group because of: (1) premature reduction of protein in the ration, and (2) low feed intake because of competition at the feed trough. Thus it seems logical to expect lower than average gains on these pigs following their attaining a weight of 70 pounds. Figure 4 would seem to bear out this hypothesis.

The greater slope of the curve as it approaches the 200-pound weight is apparently due to the faster growing pigs rather than the slower ones. Comparison of the curves for pigs requiring 14 and 18 weeks, respectively, of feeding to reach market weight show the rate of gain for the latter group to be practically constant after the pigs reach 100 pounds in weight, while the rate for the former group continues to increase (Figure 4). This must

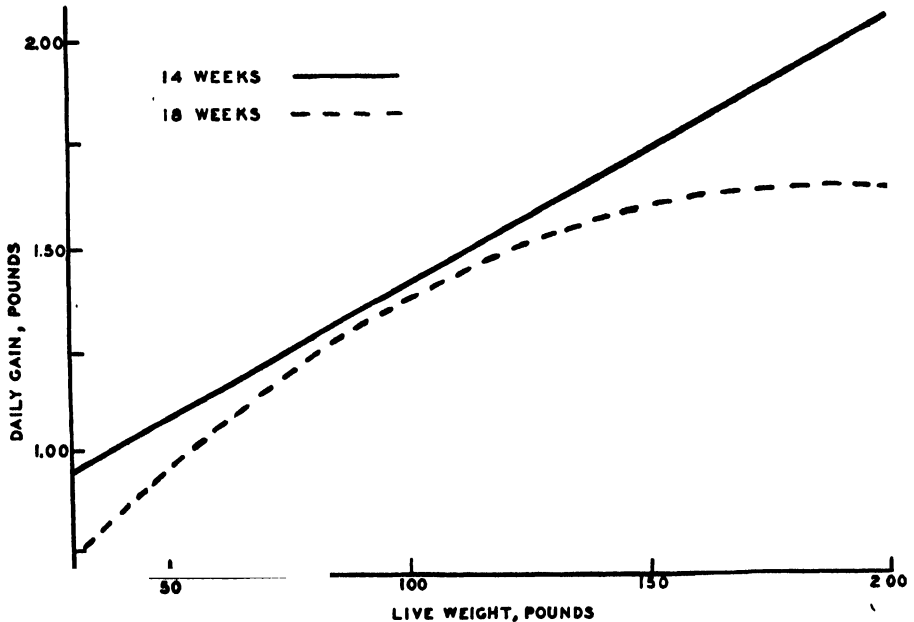


FIGURE 4. Average daily gain of pigs requiring 14 and 18 weeks of test feeding to reach 200 lbs. live weight.

surely mean the 18-week group could have consumed more feed if they had had access to it. Since the 14-week pigs were out of the picture, at this time, the feed allowance must be the limiting factor in feed consumption.

SUMMARY

Data are presented indicating average daily live weight increases of group-fed Yorkshire pigs at various live weights from 30 to 200 pounds.

This study indicates that the rates of live weight increase for bacon type pigs are influenced by feeding practice.

REFERENCES

1. ASHTON, G. C., and E. W. CRAMPTON. Growth and feed consumption of bacon hogs. II. Rates of gain and feed consumption according to weight of pig. *Sci. Agri.* 23 : 11. 1943.
2. CRAMPTON, E. W. Growth and feed consumption of bacon hogs. *Sci. Agri.* 19 : 12. 1939.
3. FISHER, R. A. Statistical methods for research workers. Oliver and Boyd. London. 7th Edition, p. 142. 1938.

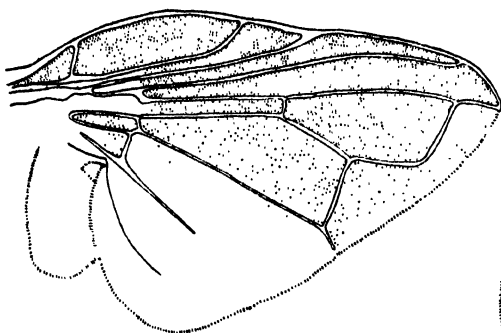
ERRATUM

In the article entitled, "A revision of the North American species of the *Phasia* complex (Diptera, Tachinidae)", by A. R. Brooks in the July, 1945, issue of *Scientific Agriculture* (Vol. 25, No. 11, pp. 647-679), two plates were omitted and the legend for Plate II (page 651) is incorrect. The legend for Plate II is as follows:

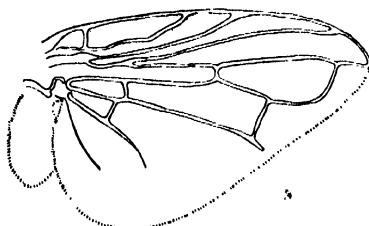
"Figures 8-13. Male wings. Drawn to same scale."

Plates III and IV appear on succeeding pages of the current (August, 1945, Vol. 25, No. 12) issue, and should be cut out and inserted in their proper place in the July issue.

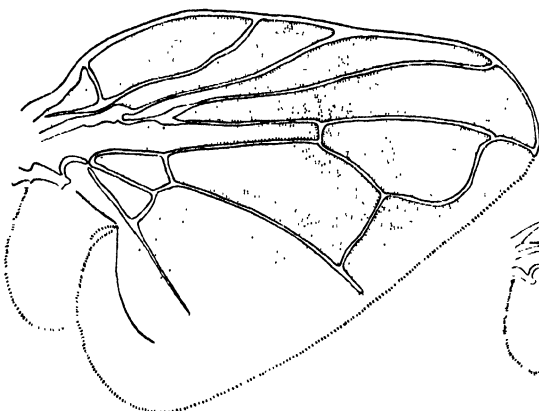
PLATE III



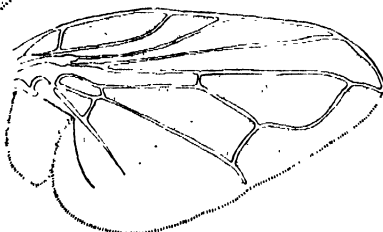
14-A. alaskensis



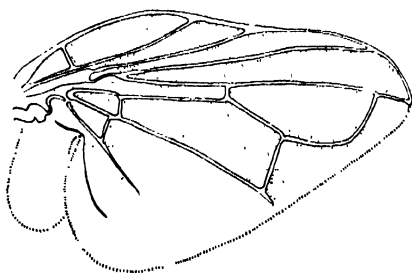
17-O. opaca



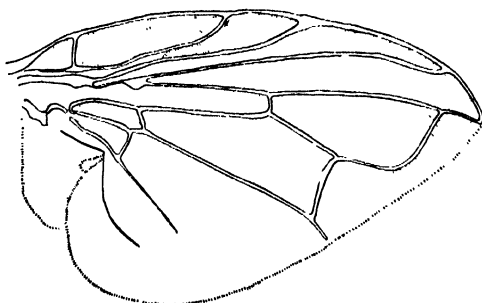
15-A. phasioides



18-O. fumosa

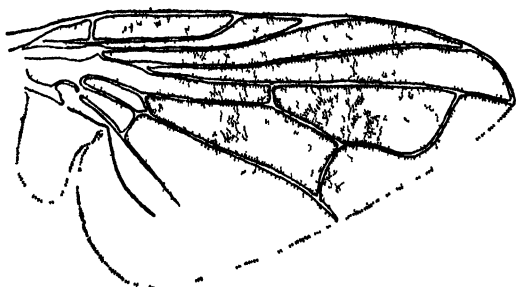
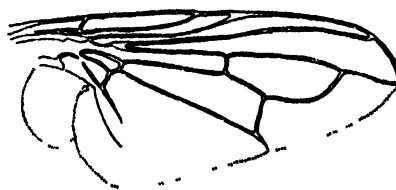
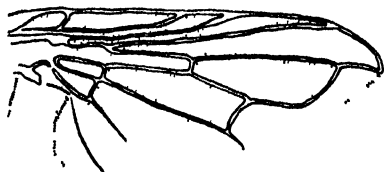
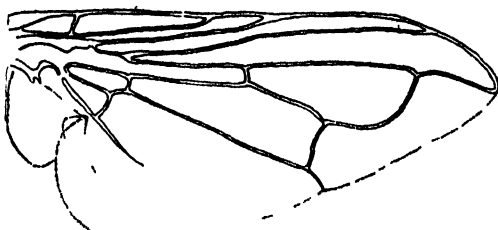
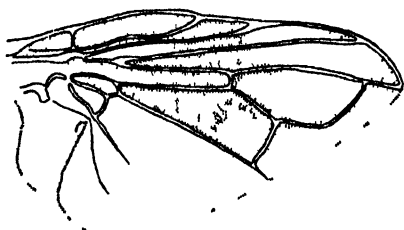
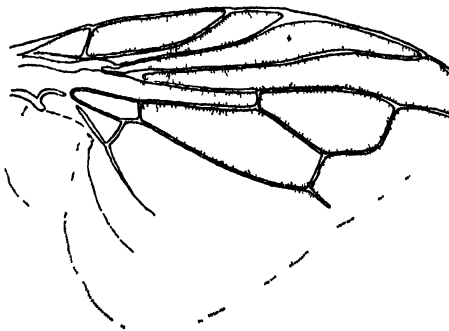
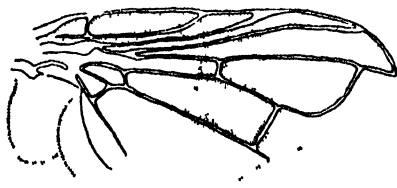
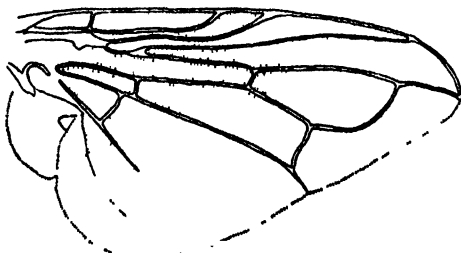
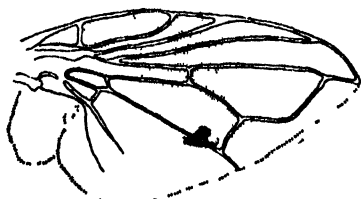


16-A. occidentalis

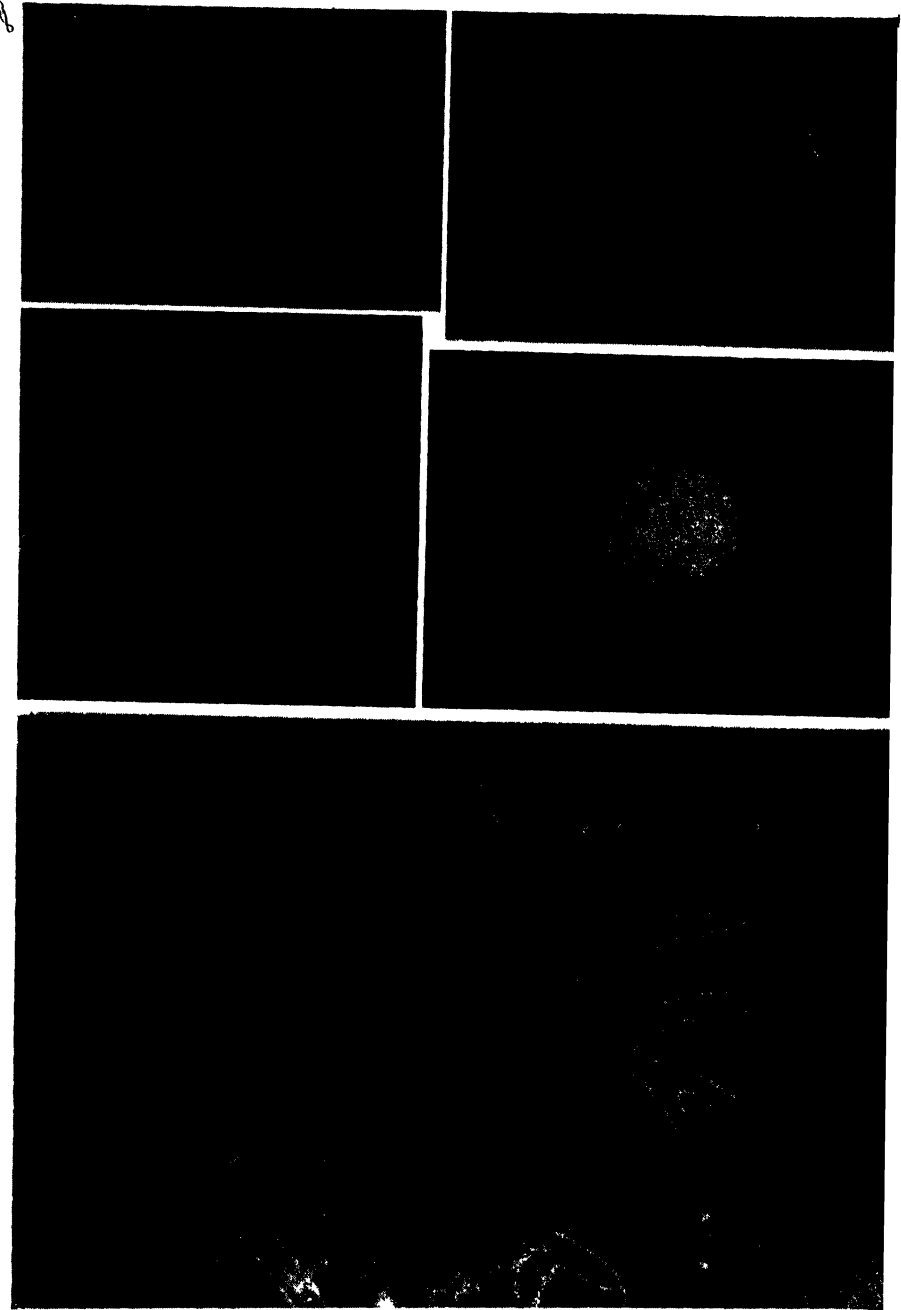


19-O. pulverea

FIGURES 14-19. Male wings. Drawn to same scale.

20-*E. diversa*25-*H. aldrichi*21-*E. subopaca*26-*P. morrisoni*22-*A. aeneoventris*27 *A. argentifrons*23 *A. robertsonii*28-*A. purpurascens*24-*A. polita*

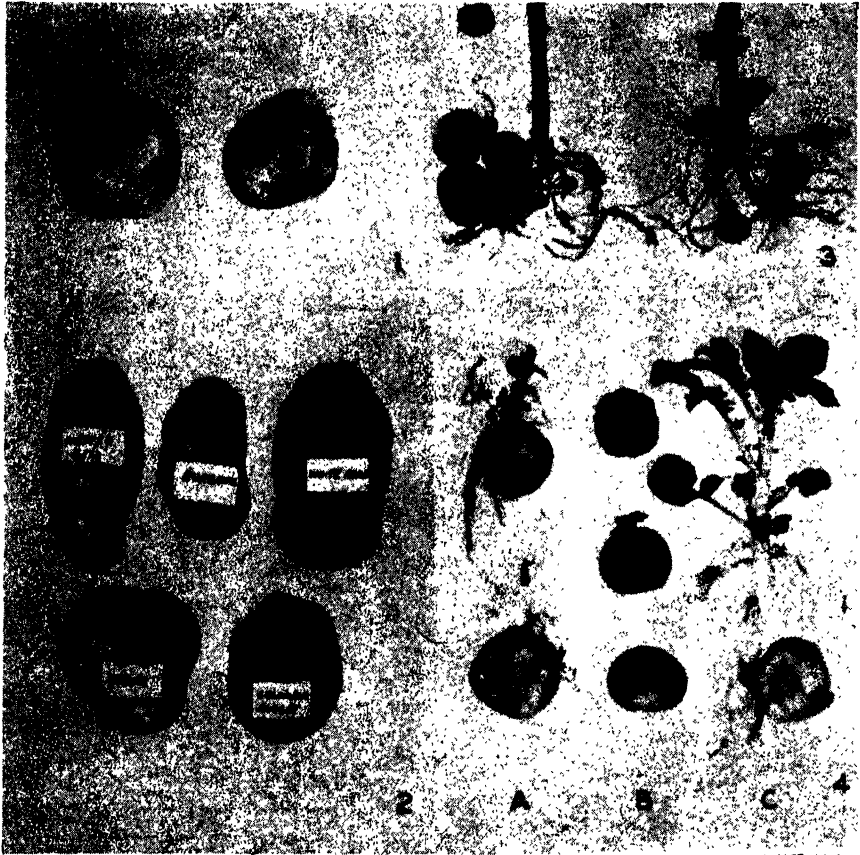
FIGURES 20-28. Male wings. FIGURES 20-24 drawn to same scale as FIGURES 7-19; FIGURES 25-28 somewhat enlarged.



Symptoms of the pink rot disease on potato tubers and plants.

1. Young tubers—Left, healthy; Right, diseased.
2. External symptoms on tubers of Netted Gem, Burbank, White Rose, Sequoia and Columbia varieties.
3. Left, check. Right, necrosis of base of stem and formation of aerial tubers caused by the fungus.
4. A and B. Showing necrosis of stems and decay of mother tubers. C. Check.

PLATE II



1 and 2. Sporangia showing sympodial branching. 3. A terminal sporangium.
4. Mature oospore. 5. Oogonium and antheridium. 6. Mycelium showing mode of
branching.

× 400

I. A. R. I. 75.

IMPERIAL AGRICULTURAL RESEARCH
INSTITUTE LIBRARY
NEW DELHI.

[illegible]